Istituto Nazionale di Fisica Nucleare

Charm hadronisation in proton–proton and proton–Pb collisions

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Quark gluon plasma characterisation with heavy-flavour probes

Trento, 15-19 November 2021

Physics motivation

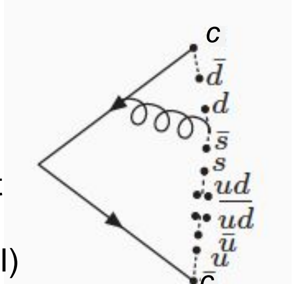
Heavy Quarks (charm and beauty) are produced only "initially" in hard-scattering processes with cross section calculable with pQCD

→ **"perturbative" probes of transition from quarks to hadrons in all collision systems**
→ measurement of cross sections and relative abundances of charm-hadron species provides a test for models incorporating (semi)dynamical description of hadronisation or based on a statistical approach

Main hadronisation model categories (in a simplified scheme)

Fragmentation "in vacuum"

Light quark/diquark pairs popping out from QCD color-confinement potential (← strings in Lund model)

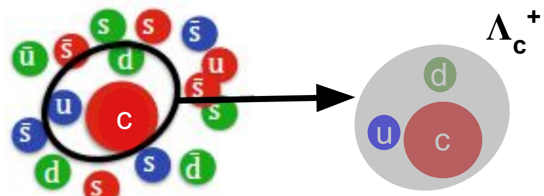


Courtesy of C. Bierlich

Reproduces phenomenological fragmentation functions used in pQCD-based calculations

Coalescence

Combine already existing quarks

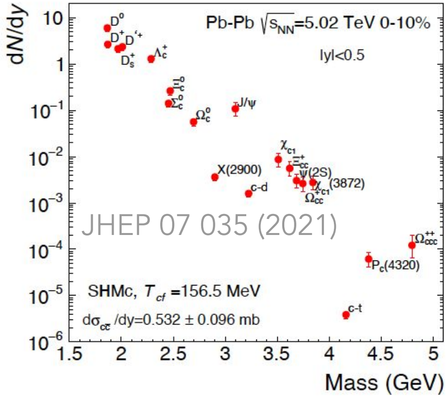


Courtesy of F. Grosa

Originally introduced and thought to be suited for nucleus-nucleus collisions

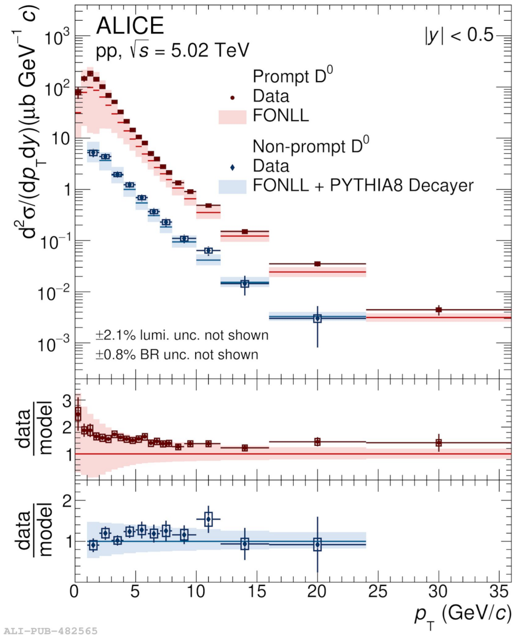
Statistcal hadronisation

Yields defined only by hadron masses and system properties



Factorisation: a very successful framework for HF mesons!

$$\frac{d\sigma^{D}}{dp_{T}}(p_{T}^{D};\mu_{F};\mu_{R}) = PDF(x_1,\mu_F)\,PDF(x_2,\mu_F) \otimes \frac{d\sigma^{c}}{dp_{T}^{c}}(x_1,x_2;\mu_F;\mu_R) \otimes D_{c\to D}\left(z=\frac{p_D}{p_c};\mu_F\right)$$

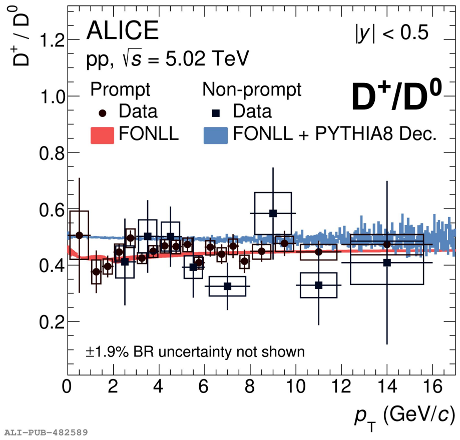


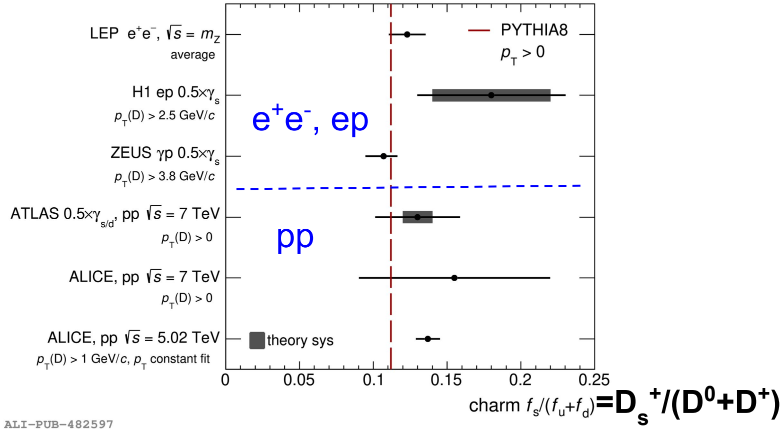
JHEP 05 (2021) 220

FONLL: JHEP 10 (2012) 137

Fragmentation functions ($D_{c\text{->}D}$) often **assumed** "**universal**": once constrained to e^+e^- and ep data they are used in different collision systems and energies.

Naïve expectation: ratios of particle-species yields independent from collision system



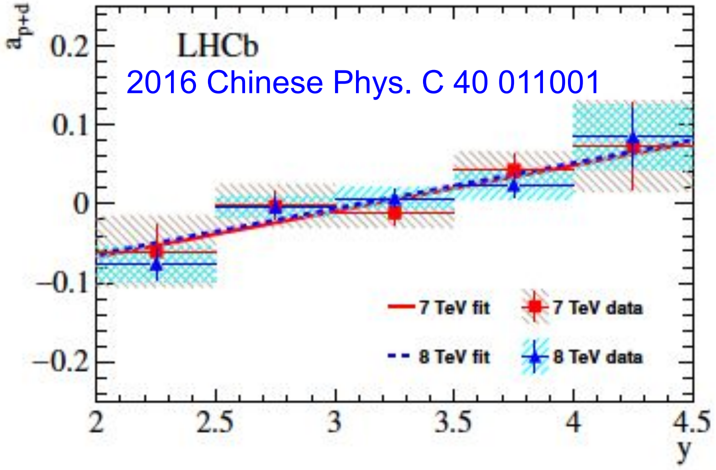


Prompt and non-prompt D mesons (including D_s^+) follow expectations… **does it hold for baryons?**
Up to what extent fragmentation functions tuned on e^+e^- can be effective in pp or heavy-ion collisions?

Beam remnants and drag effect, R_{AA}

Indication for a rapidity-dependent ratio of $\Lambda_b/\overline{\Lambda}_b$, suggesting some baryon-number transport from beam particles to $\Lambda_b \leftarrow$ **string drag/leading-quark effect?**

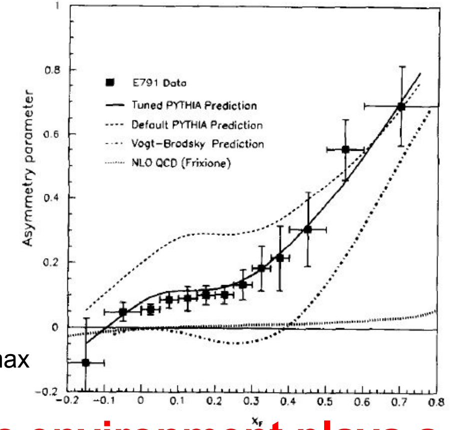
J.L. Rosner, PRD 90 014023 (2014); PRD 86 014011 (2012)



Similar effect observed for charm mesons (D^+) long ago in π-nucleus collisions (E791, E769, WA82)

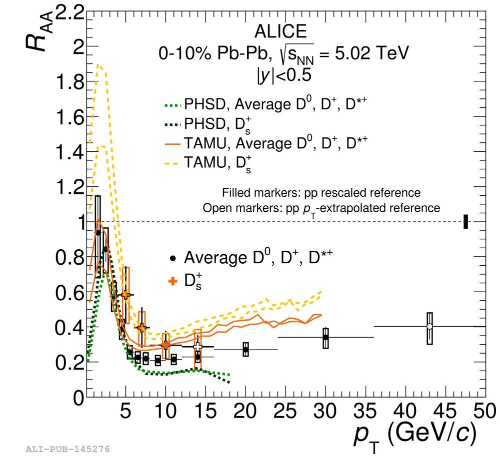
$$A(x_F, p_t^2) \equiv \frac{\sigma_L - \sigma_{NL}}{\sigma_L + \sigma_{NL}}.$$

E791, PLB 371 (1996) 157-162



$x_F = p_z/p_{z,\,max}$

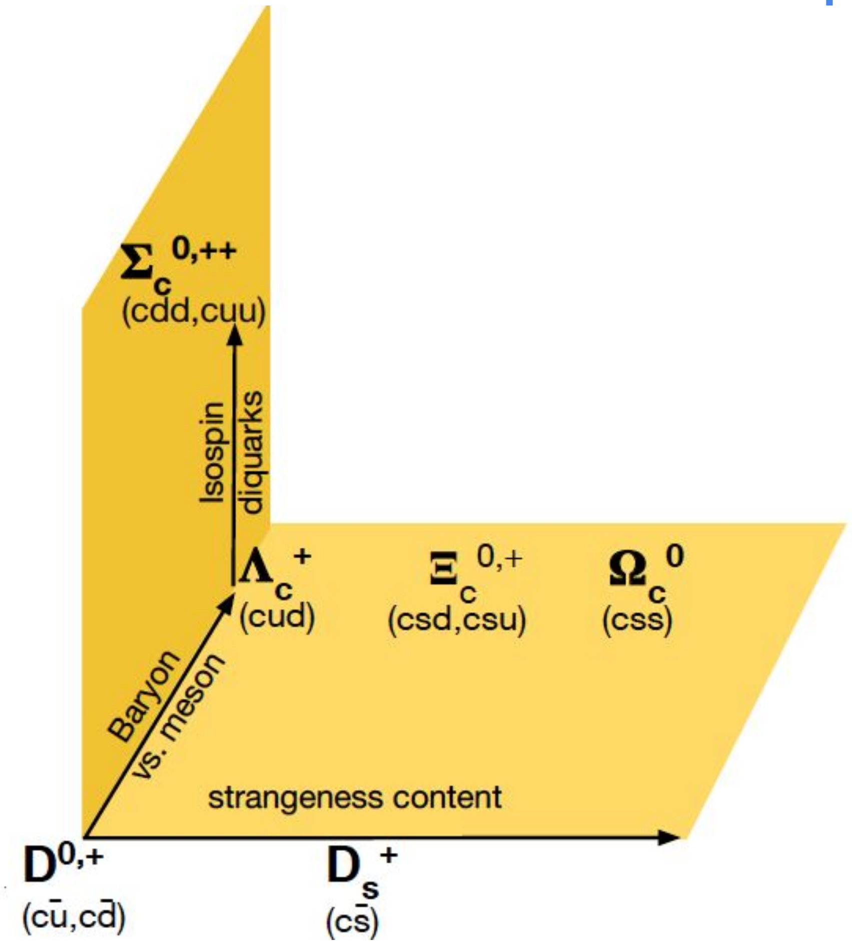
And the heavy-ion community knows that a medium matters...



Suggest that **hadronic environment plays a role**

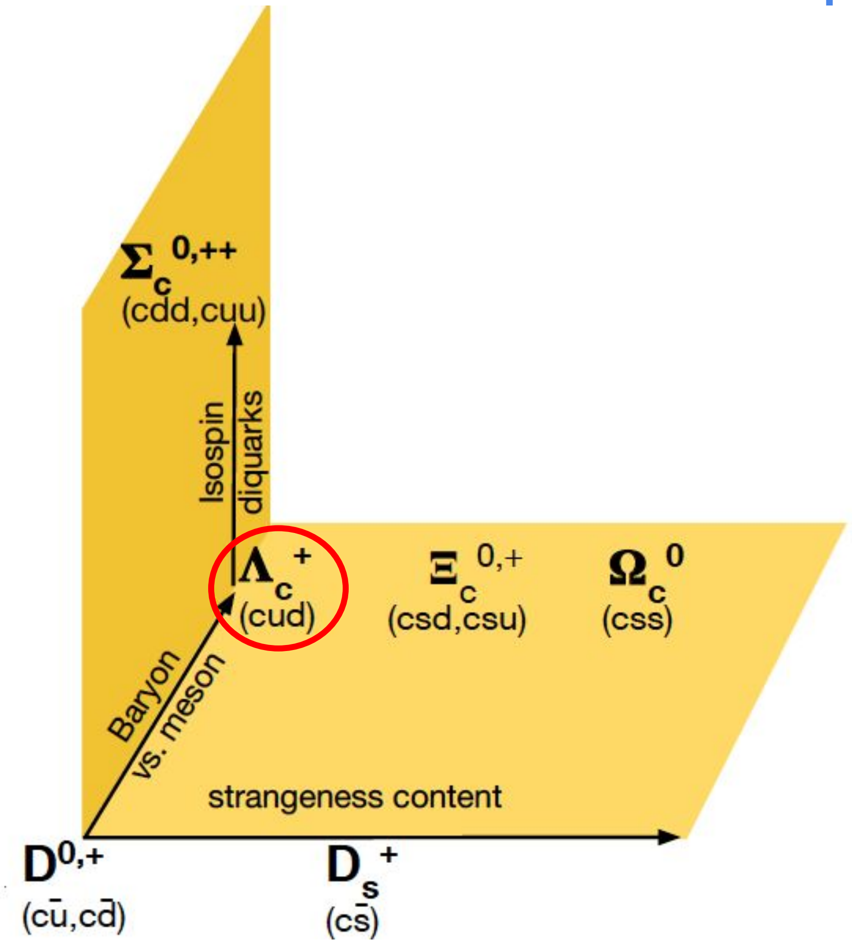
Up to what extent? how does the hadronisation dynamics change in different systems?

Several arrows in the quiver



Particle	Mass (GeV/c^2)
D^0	1.865
D^+	1.870
D_s^+	1.968
Λ_c^+	2.286
$\Sigma_c^{0,++}$	2.454
Ξ_c^0	2.470
Ξ_c^+	2.468
Ω_c^0	2.695

Several arrows in the quiver



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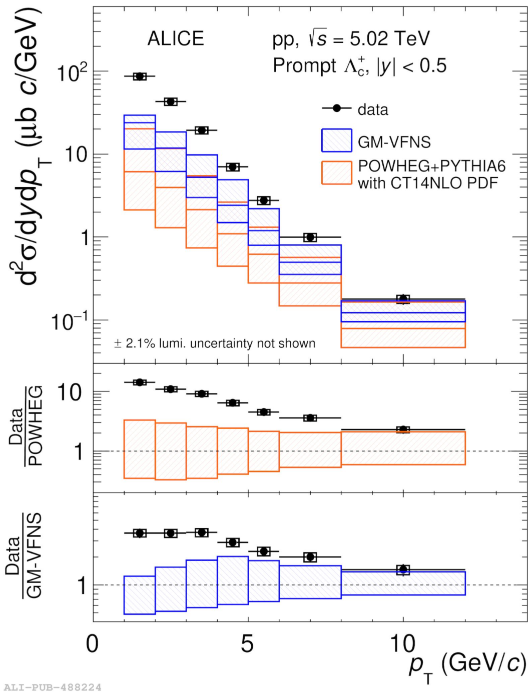
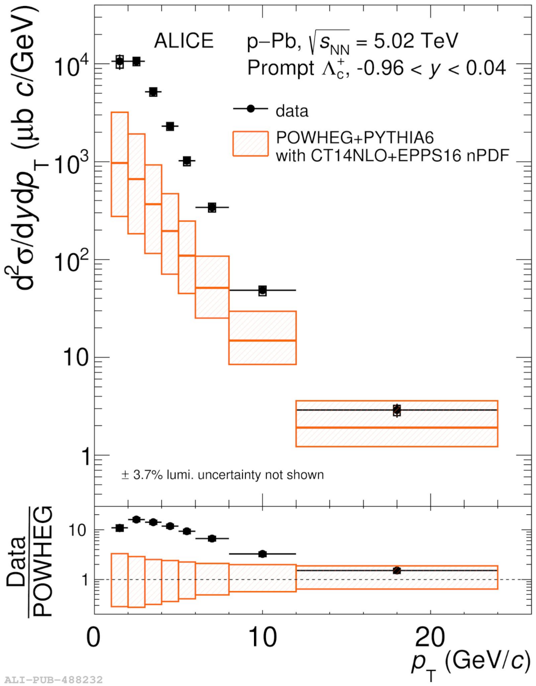
Λ_c^+ cross section in pp and p-Pb collisions at $\sqrt{s_{NN}} = 5$ TeV

PRC 104 054905 (2021)
PRL 127 202301 (2021)

pp



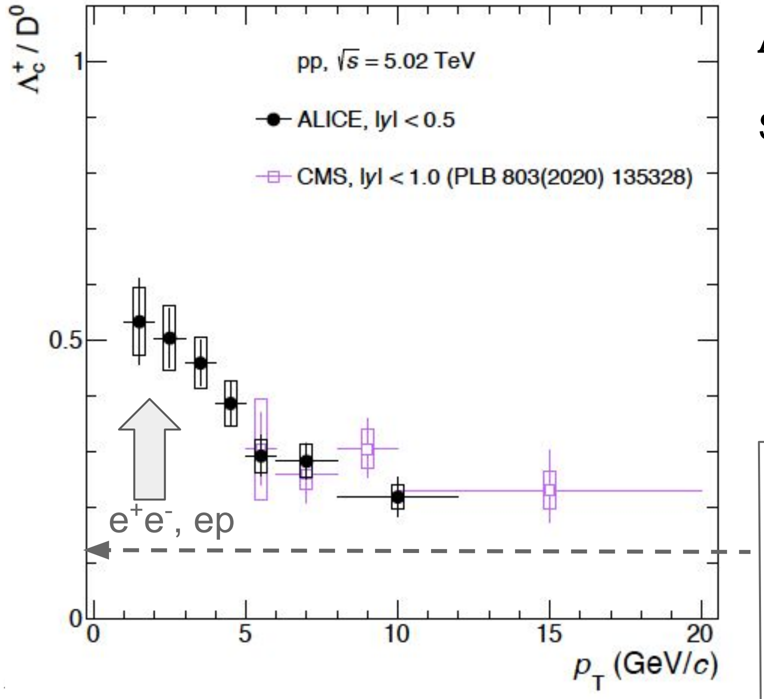
p-Pb



Λ_c^+ production significantly underestimated by pQCD-based models

GM-VFNS: PRD 101 (2020) 114021
POWHEG: JHEP 09 (2007) 126
PYTHIA6: JHEP 05 (2006) 026
CT14 NLO: Phys. Rev. D 93, 033006 (2016)

Λ_c^+/D^0 ratio in pp collisions at 5 TeV



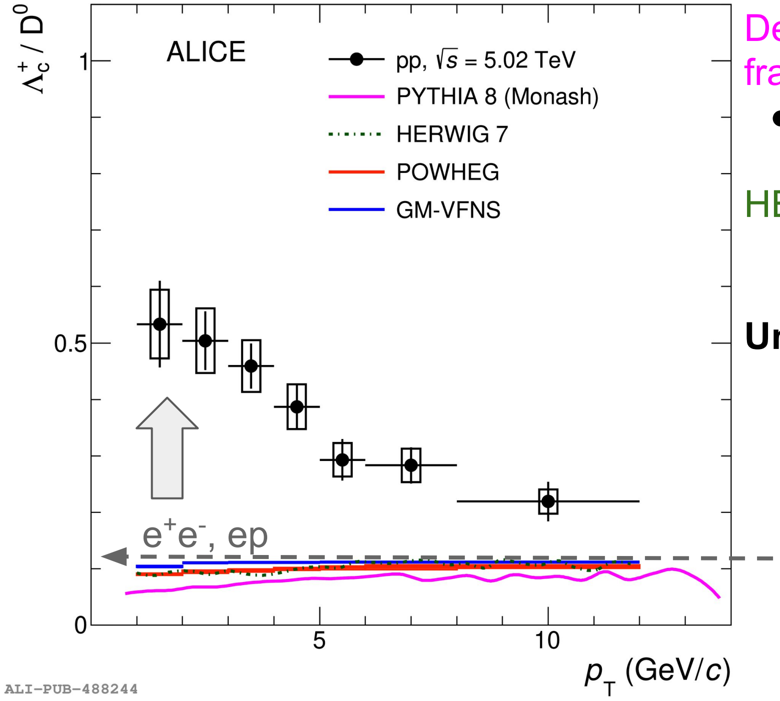
Λ_c^+/D^0 ratio higher (x4-5) values at low p_T than e^+e^-, ep

Significantly decreasing with p_T

	$\Lambda_c^+/D^0 \pm$ stat. $\pm$ syst.	System	$\sqrt{s}$ (GeV)	Notes
ALICE	$0.51 \pm 0.04 \pm 0.04^{+0.01}_{-0.02}$	pp	5020	$p_T > 0, \lvert y\rvert < 0.5$
ALICE	$0.43 \pm 0.03 \pm 0.05^{+0.05}_{-0.03}$	p–Pb	5020	$p_T > 0, -0.96 < y < 0.04$
CLEO [16]	$0.119 \pm 0.021 \pm 0.019$	e^+e^-	10.55	
ARGUS [15, 17]	0.127 ± 0.031	e^+e^-	10.55	
LEP average [18]	$0.113 \pm 0.013 \pm 0.006$	e^+e^-	91.2	
ZEUS DIS [21]	$0.124 \pm 0.034^{+0.025}_{-0.022}$	e^-p	320	$1 < Q^2 < 1000$ GeV^2, $0 < p_T < 10$ GeV/c, $0.02 < y < 0.7$
ZEUS γp, HERA I [19]	$0.220 \pm 0.035^{+0.027}_{-0.037}$	e^-p	320	$130 < W < 300$ GeV, $Q^2 < 1$ GeV^2, $p_T > 3.8$ GeV/c, $\lvert\eta\rvert < 1.6$
ZEUS γp, HERA II [20]	$0.107 \pm 0.018^{+0.009}_{-0.014}$	e^-p	320	$130 < W < 300$ GeV, $Q^2 < 1$ GeV^2, $p_T > 3.8$ GeV/c, $\lvert\eta\rvert < 1.6$

ALICE, arXiv:2011.06079, PRC 104 054905 (2021)
ALICE, arXiv:2011.06078, PRL 127 202301 (2021)
CMS, PLB 803 13428 (2020)

Λ_c^+/D^0 ratio in pp collisions at 5 TeV



Default PYTHIA8 (Monash, EPJC 74 (2014) 3024), standard Lund string fragmentation

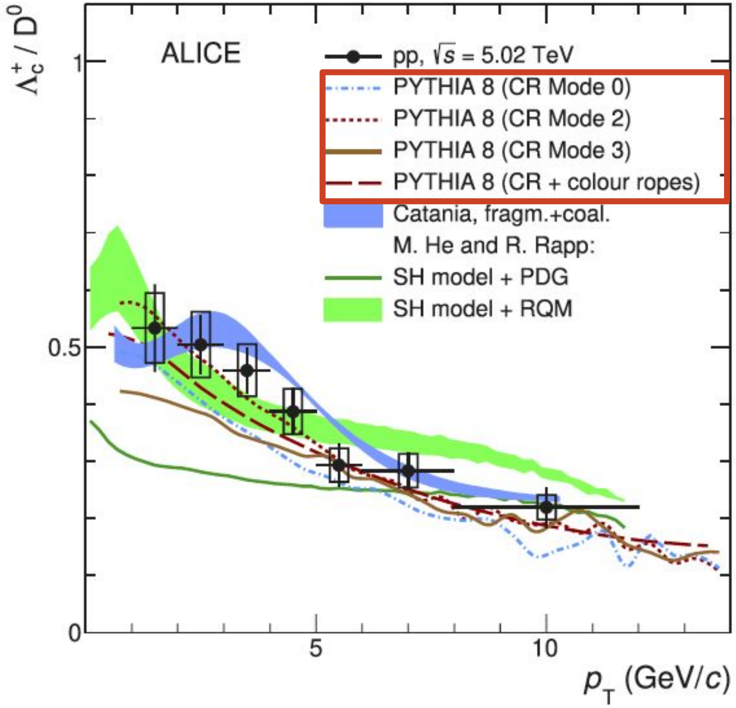
- Hadronisation of different MPI products largely independent

HERWIG7 (EPJC 58 (2008) 639-707), cluster hadronisation

Undershoot data by factor about 5 and do not catch p_T shape

ALICE, arXiv:2011.06079, PRC 104 054905 (2021)
ALICE, arXiv:2011.06078, PRL 127 202301 (2021)

Λ_c^+/D^0 ratio in pp collisions at 5 TeV

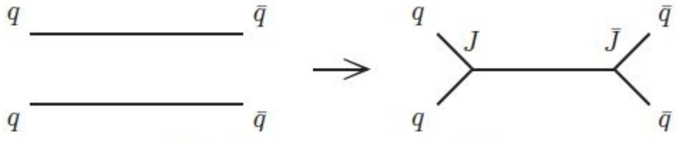


ALICE, arXiv:2011.06079, PRC 104 054905 (2021)
ALICE, arXiv:2011.06078, PRL 127 202301 (2021)

Data described by:

PYTHIA8 with String Formation beyond Leading Colour approximation (JHEP 1508 (2015) 003).
More complete and realistic (=closer to QCD) colour-reconnection (CR) scheme
- "***...between which partons do confining potentials arise?***"

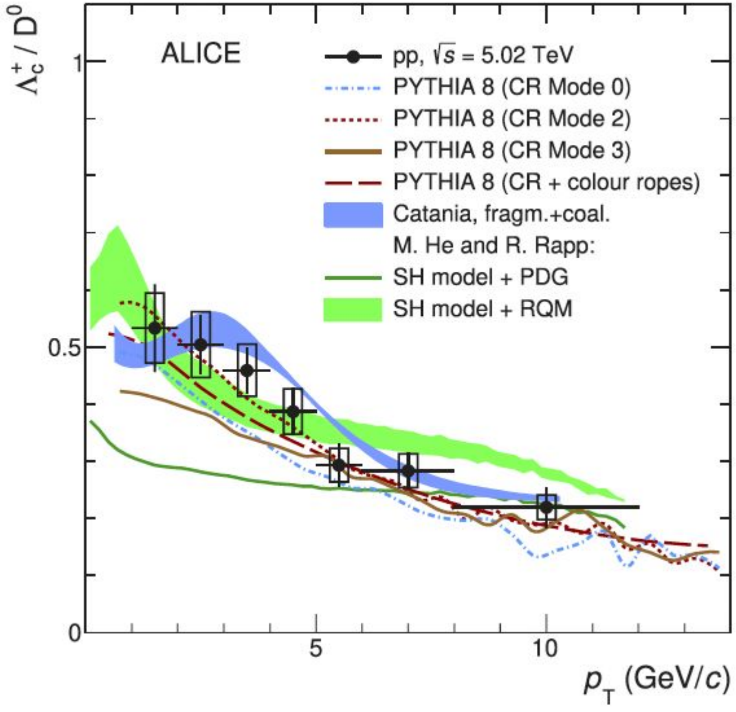
Junction reconnection topologies → enhance baryons.



(b) Type II: junction-style reconnection

Λ_c^+/D^0 ratio in pp collisions at 5 TeV

More in S. Plumari's talk



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PYTHIA8 with String Formation beyond Leading Colour

Catania model: coalescence + "vacuum" fragmentation

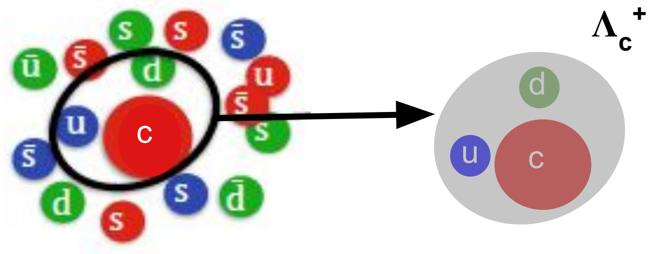
(arxiv.org 2012.12001)

Expanding system of thermalised light quarks and gluons

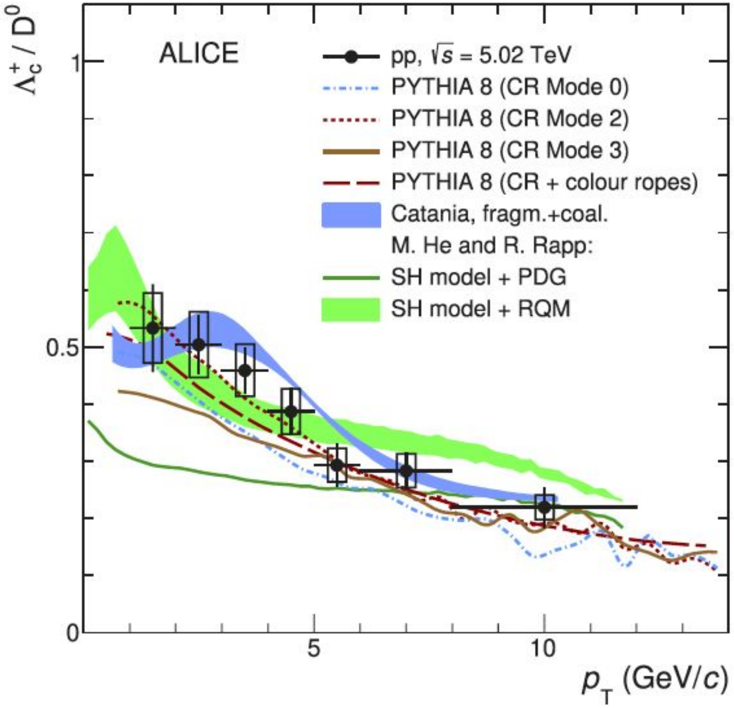
"Sudden" (fixed temperature) coalescence

Coalescence probability from Wigner formalism

Charm quarks that do not coalesce, fragment



Λ_c^+/D^0 ratio in pp collisions at 5 TeV



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Catania model: coalescence + "vacuum" fragmentation

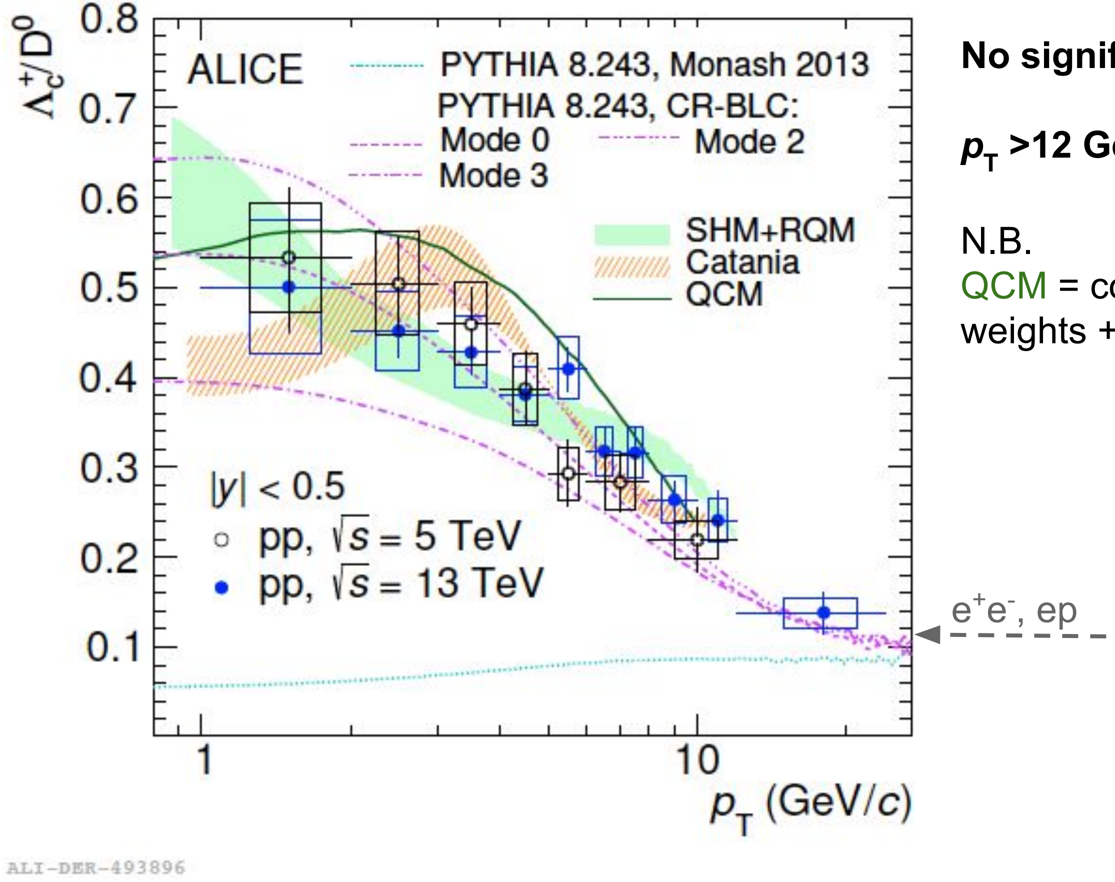
SH+PDG/RQM, PLB 795 117-121 (2019):
Hadron abundances based on **statistical hadronisation model** + (RQM) large feed-down from **augmented set of charm-baryon states**

More in Min He's talk

ALICE, arXiv:2011.06079, PRC 104 054905 (2021)
ALICE, arXiv:2011.06078, PRL 127 202301 (2021)

Λ_c^+/D^0 ratio in pp collisions at 5 TeV and 13 TeV

arxiv 2106.08278



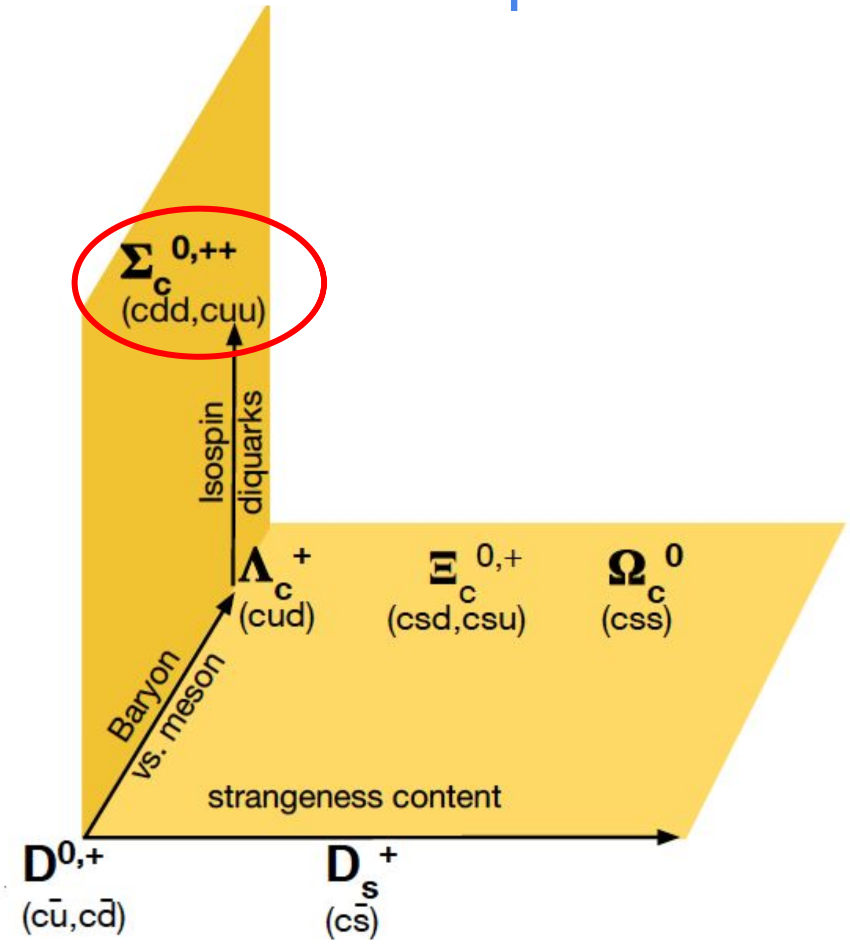
No significant dependence on collision energy

p_T >12 GeV/c: approaching e^+e^- values?

N.B.

QCM = coalescence model based on statistical weights + “equal quark-velocity” (EPJC 78, 2018 4, 344)

Several arrows in the quiver



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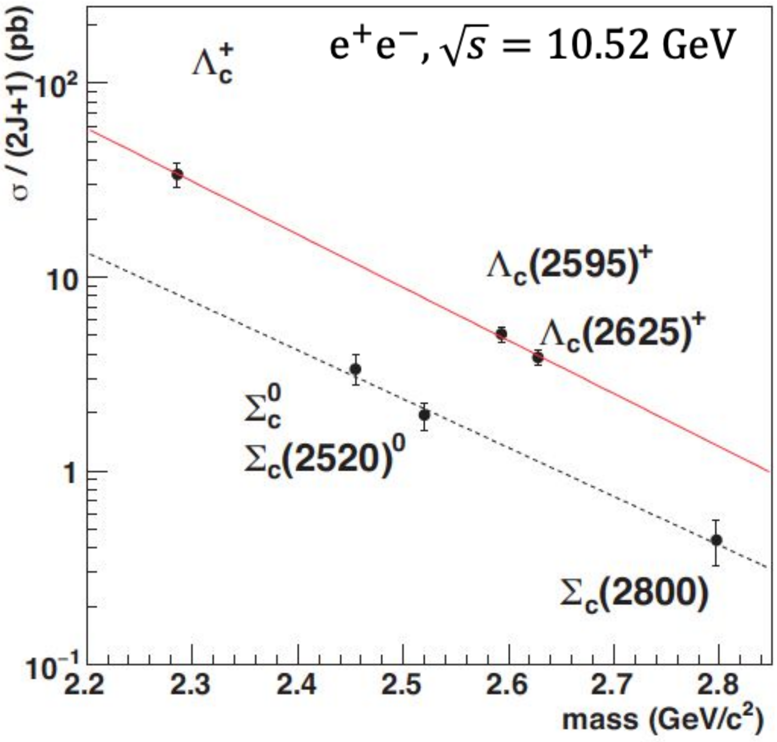
$\Sigma_c^{0,++}$ production and $\Lambda_c^+ \leftarrow \Sigma_c^{0,++}$ feedown

Belle, PRD 97, 072005 (2018)

More in M. Faggin's talk



e^+e^- collisions: production of Σ_c states suppressed w.r.t. Λ_c states

In string fragmentation models charm baryons formed by combining initially produced c quarks with light-quark diquarks, produced in pair in string breaking

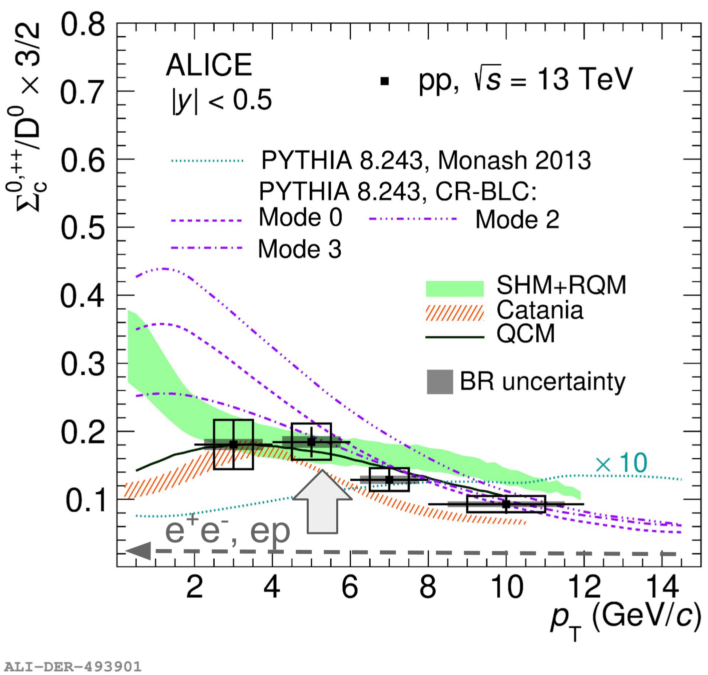
Λ_c (isospin = 0) needs diquark with spin = 0 $(ud)_0$
Σ_c (isospin = 1) needs diquark with spin = 1 $(ud,dd,uu)_1$

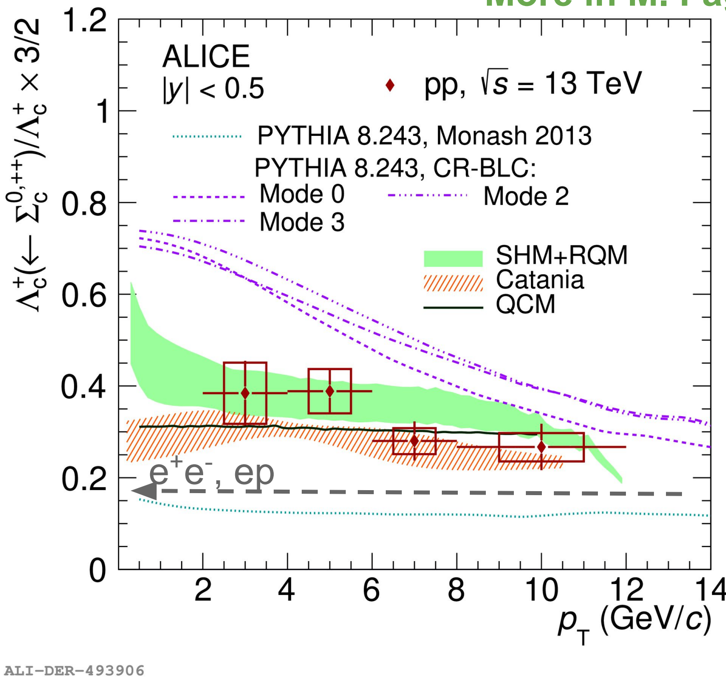
$(ud,dd,uu)_1$ larger mass than $(ud)_0$ mass → suppression

$\Sigma_c^{0,++}$/D^0 and $\Lambda_c^+ \leftarrow \Sigma_c^{0,+,++}$ feedown in pp at 13 TeV

arxiv 2106.08278

More in M. Faggin's talk





$\Sigma_c^{0,+,++}$/D^0 ratio significantly larger than in e$^+$e$^-$ collisions

About x2 increase of $\Lambda_c^+ \leftarrow \Sigma_c^{0,+,++}$ feed-down → $\Sigma_c^{0,+,++}$ "enhancement" larger than Λ_c^+ one

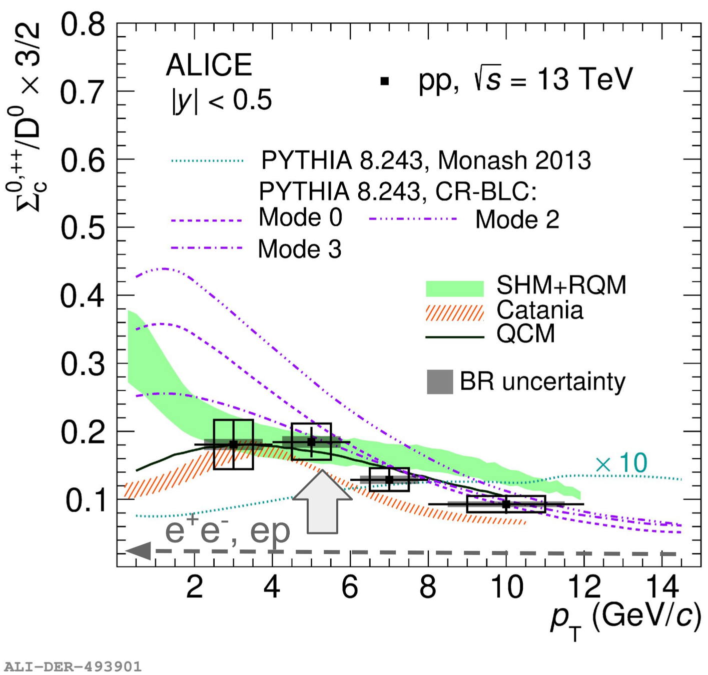
→ $\Sigma_c^{0,+,++}$produced differently in pp than e$^+$e$^-$ collisions

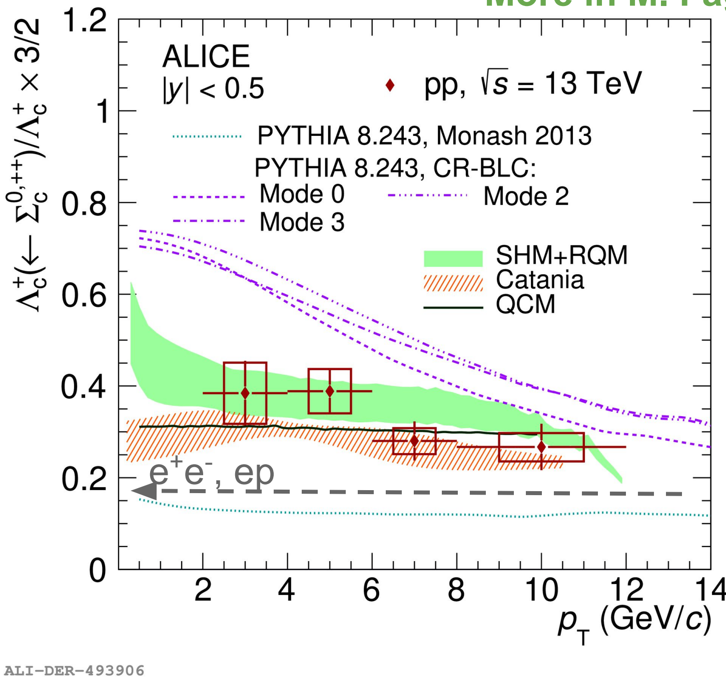
→ suppression from (ud,dd,uu)$_1$ diquark creation absent or reduced, as comparison to models suggests

$\Sigma_c^{0,++}$/D^0 and $\Lambda_c^+ \leftarrow \Sigma_c^{0,+,++}$ feedown in pp at 13 TeV

arxiv 2106.08278

More in M. Faggin's talk





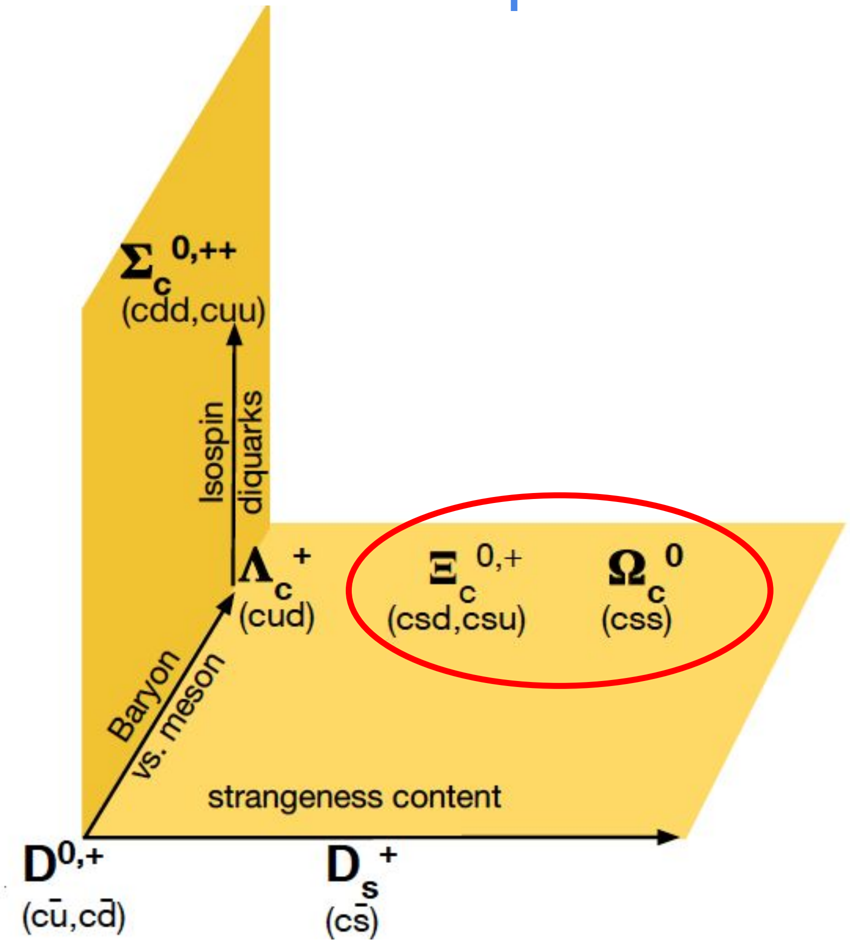
Default PYTHIA8 (Monash 2013): significantly underestimates data

PYTHIA8 with CR beyond Leading Colour: Σ_c enhanced by junction CR topologies (n.b. heavy cu, cd diquarks)

- describes $\Sigma_c^{0,+,++}$/D^0 but overestimates $\Lambda_c^+ \leftarrow \Sigma_c^{0,+,++}$/D^0

Catania, QCM and SHM+RQM models describe both ratios

Several arrows in the quiver



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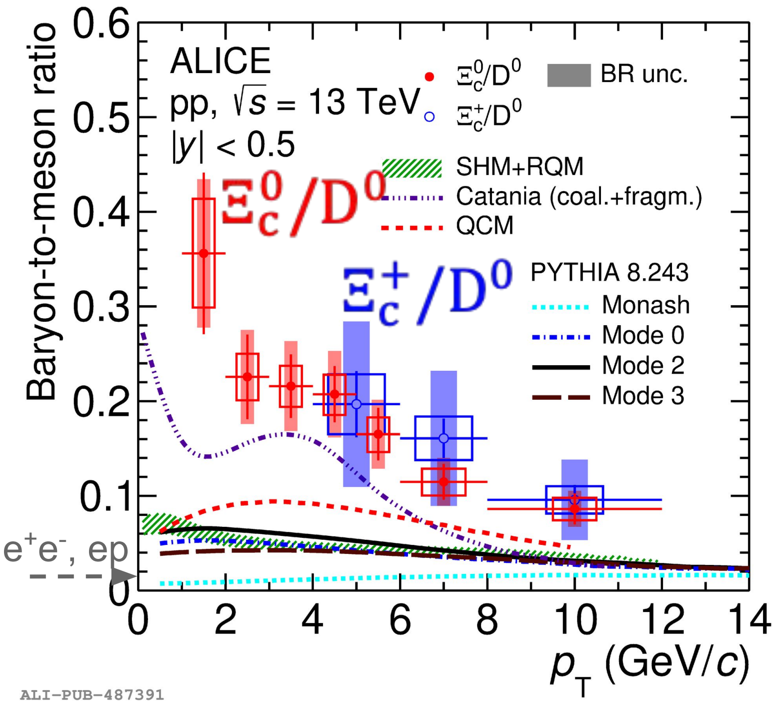
Charm-strange baryons: $\Xi_c^{0,+}$

arxiv 2105.05187



ALI-PUB-487391

$\Xi_c^{0,+}/D^0$ ratio significantly larger than in e^+e^- collisions

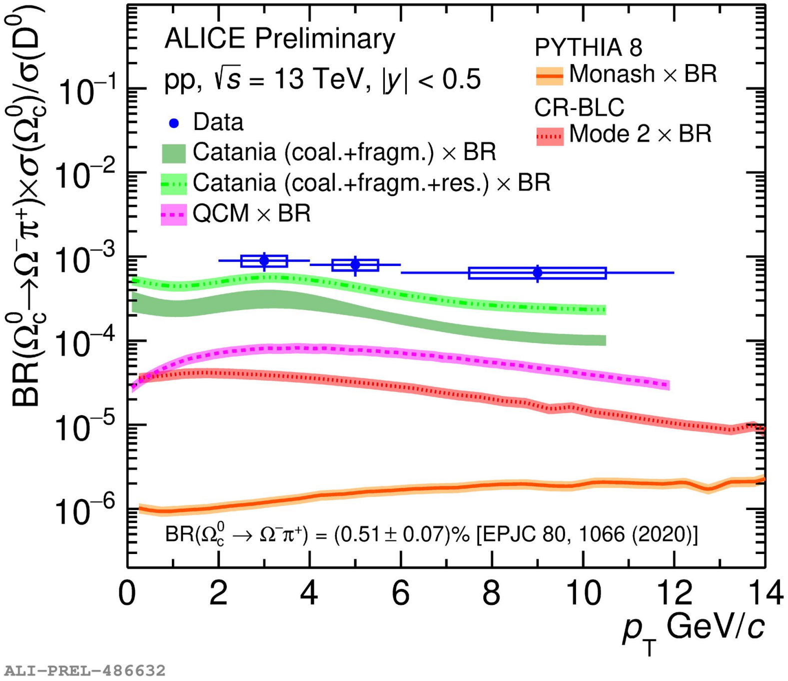
Default PYTHIA8 (Monash) largely underestimates the data

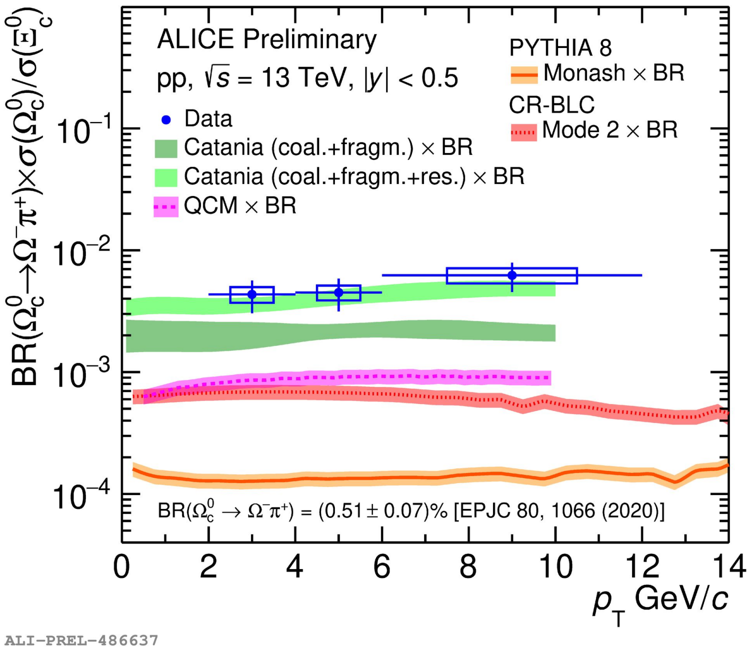
PYTHIA8 with CR-BLC (**Mode0,2,3**) and **SHM+RQM** predict ratios significantly larger than in e^+e^- but significantly underestimate the data

QCM underestimates the ratios

Catania closer to the data

Ω_c^0/D^0 and Ω_c^0/Ξ_c^0 ratios in pp collisions at 13 TeV



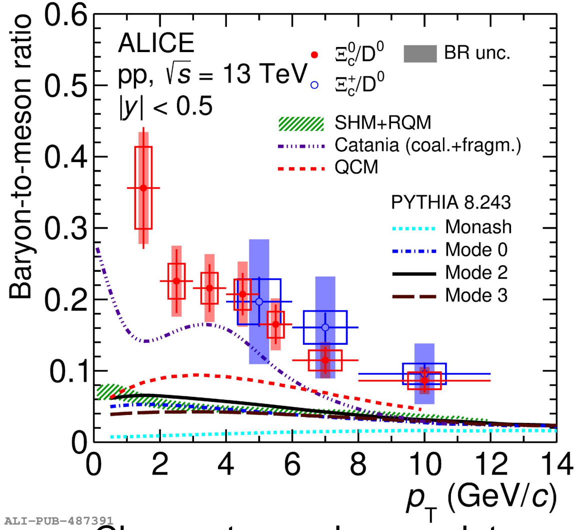


BR of $\Omega_c^0 \rightarrow \Omega^-\pi^+$: only theoretical estimate exists. Assuming this value for comparing models to data:

- Only Catania reproduce both ratios when including contribution from higher-mass resonance decays
- QCM, PYTHIA8 CR-BLC (Mode 2), and especially Monash lower by order(s) of magnitude

Not just a strange(ness) feature?

arxiv 2105.05187



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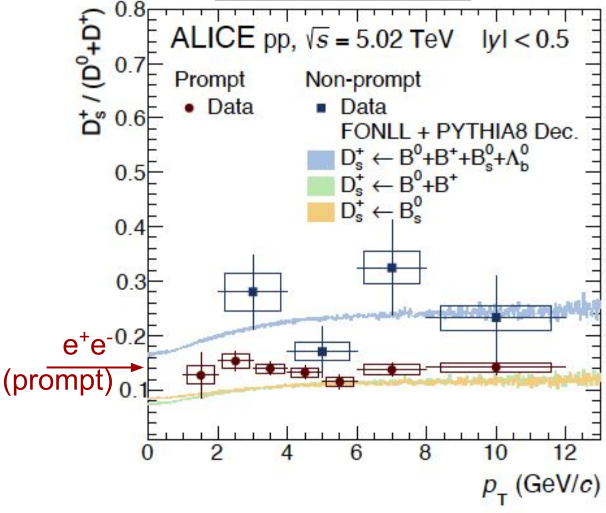
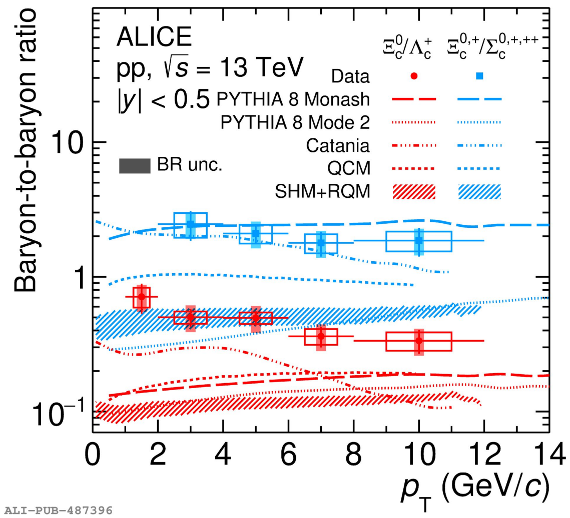


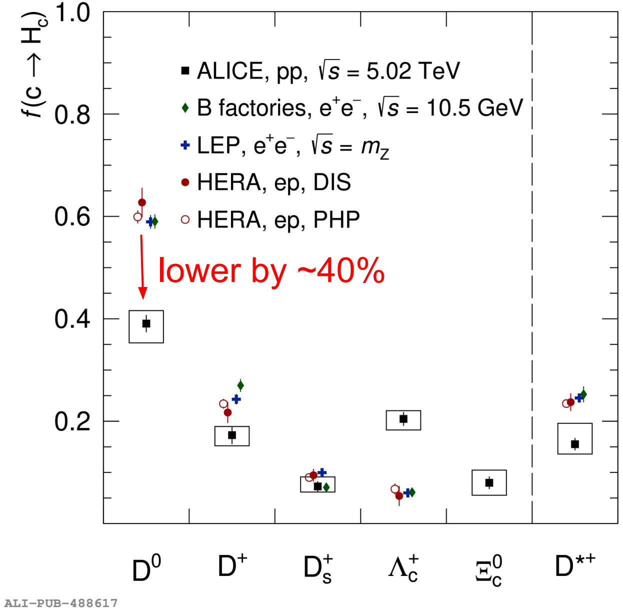


- Charm-strange baryon data underestimated by most models! Something anomalous with strange quarks?
- But $D_s^+/(D^0+D^+)$ (prompt and non-prompt) compatible with expectations from e^+e^- … **baryons are strange!**
  - Note Ξ_c^0/D^0 and Ξ_c^+/D^0 similar to D_s^+/D^0 (but large uncertainties)
- $\Xi_c^{0,+}/\Sigma_c^{0,+,++}$ ratio described by default PYTHIA8 (Monash)! (by Catania as well)
  → similar suppression in e^+e^-? Related to diquark rather than quarks?
  (note mass of spin-1 $(dd,ud,uu)_1$ diquarks might be similar to spin-0 $(us,ds)_0$ diquarks)
  Does this also connect to similarity of baryon-to-meson ratios in HF and LF sector?

- $\Xi_c^{0,+}/\Lambda_c^+$ ratio underestimated by all models

Impact on branching fractions and charm cross section

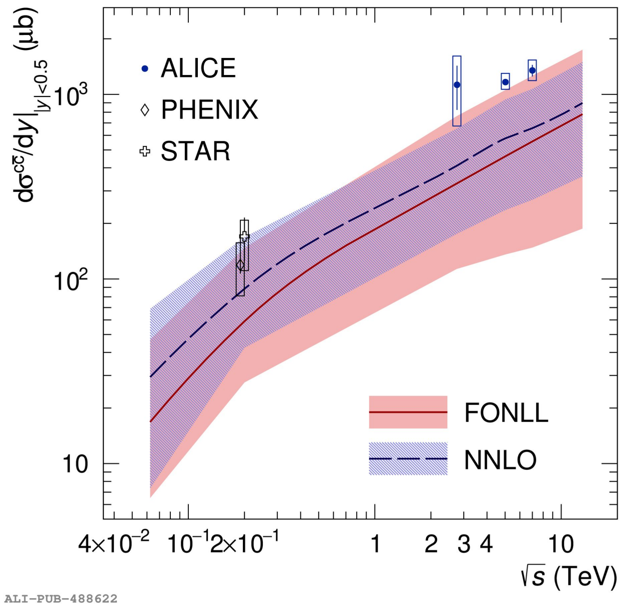
arxiv 2105.06335



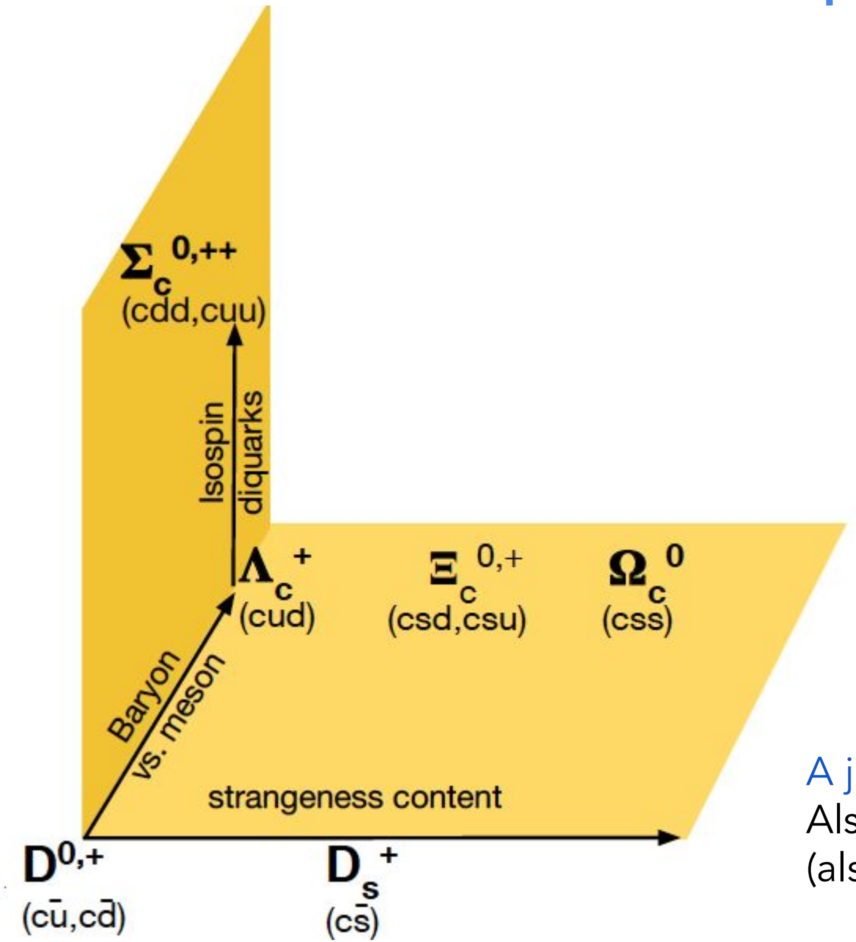
Measured baryon-to-meson ratios imply **violation of universality of fragmentation fractions (FF) already in pp collisions**:
→ cannot rely on e^+e^- FF to calculate charm cross section from D meson data
→ new FF estimated in pp collisions at 5 TeV from all measured hadron-species cross sections

Total $c\bar{c}$ cross section at $|y|<0.5$ estimated at 5 TeV from all measured particle-species cross sections

Re-evaluated at 2.76 and 7 TeV using new D^0 FF
40% higher values w.r.t. using e^+e^- FF
On upper edge of FONLL and NNLO



Several arrows in the quiver



A jump in mass with beauty!
Also with non-prompt signals
(also leptons and J/Ψ)

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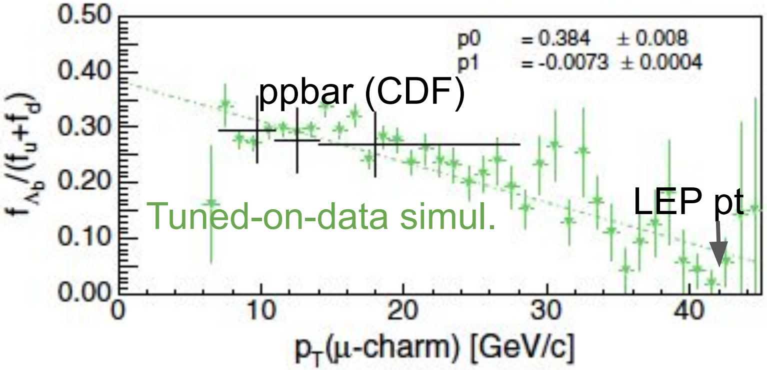
$B^{0,+}$	5.280
B_s^0	5367
Λ_b^0	5620

Beauty baryons vs. mesons at LEP, Tevatron and LHC

HFLAV, EPJC 77 (2017) 895

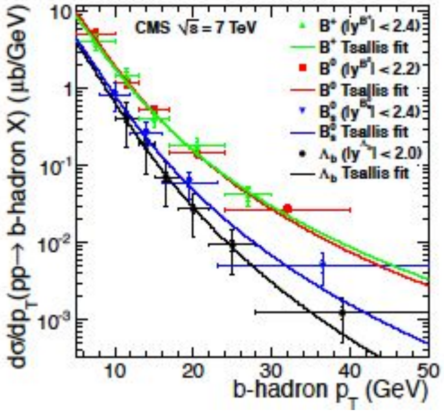
b hadron	Fraction at Z[%]	Fraction at $\bar{p}p$ [%]
B^+, B^0	41.2 ± 0.8	34.0 ± 2.1
B^0_s	8.8 ± 1.3	10.1 ± 1.5
b baryons	8.9 ± 1.2	21.8 ± 4.7



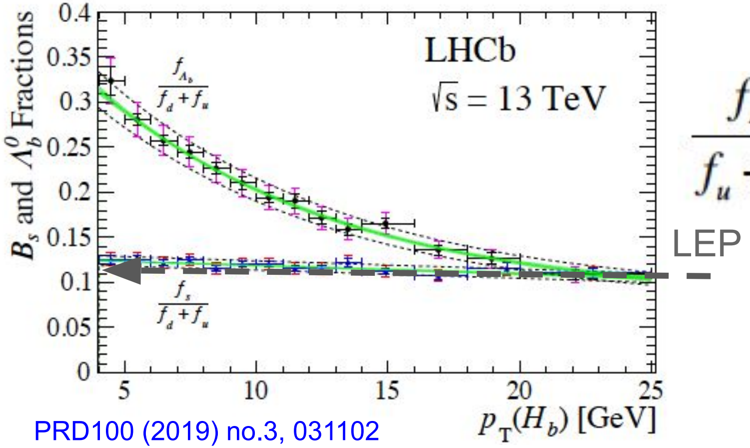
PRD 77 072003 (2008)

Suggest p_T-dependent fragmentation fraction, possibly influenced by hadronic environment

At LHC: precise Λ_b^0 measurements indicate clear dependence of baryon-to-meson ratio on p_T



CMS, PLB 714 (2012) 136



PRD100 (2019) no.3, 031102

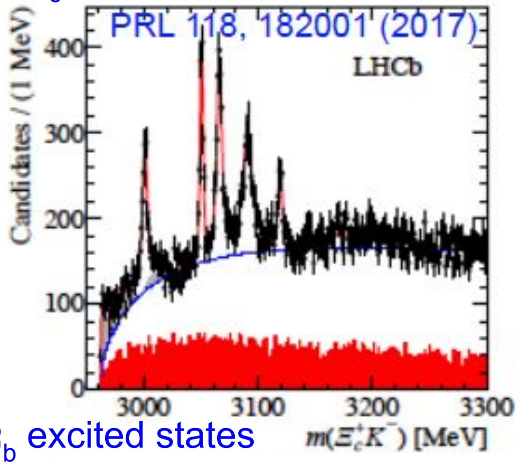
$$\frac{f_{\Lambda_b}}{f_u+f_d}$$

at low p_T significantly higher (x3) than LEP data

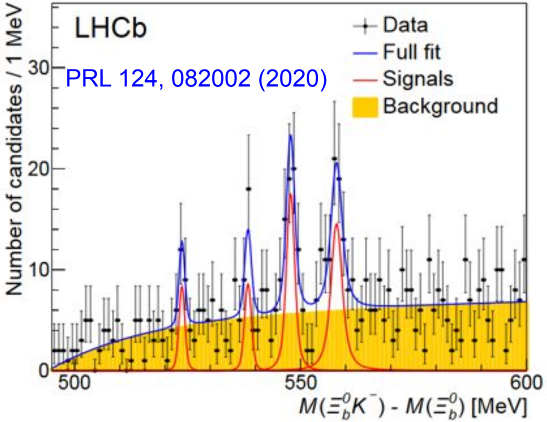
Similar effect in charm and beauty sectors

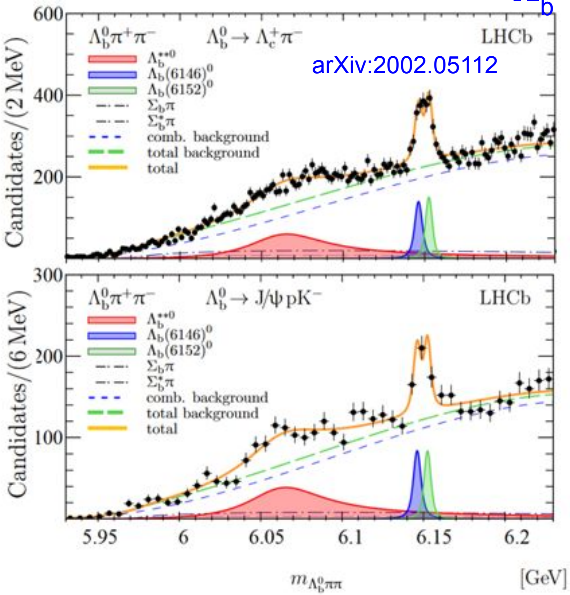
Higher-mass states: new states popping up

Ω_c excited states

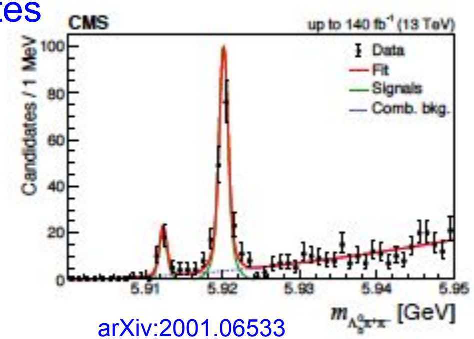


Ω_b excited states

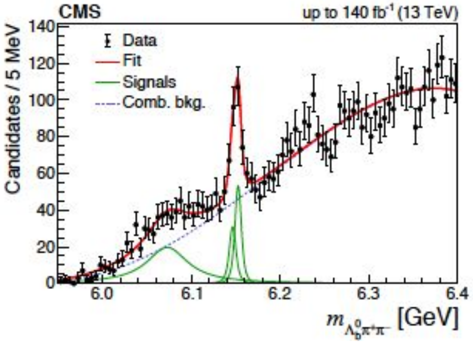


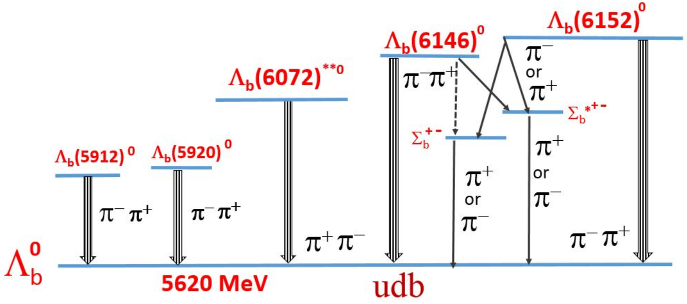


Λ_b excited states



arXiv:2001.06533

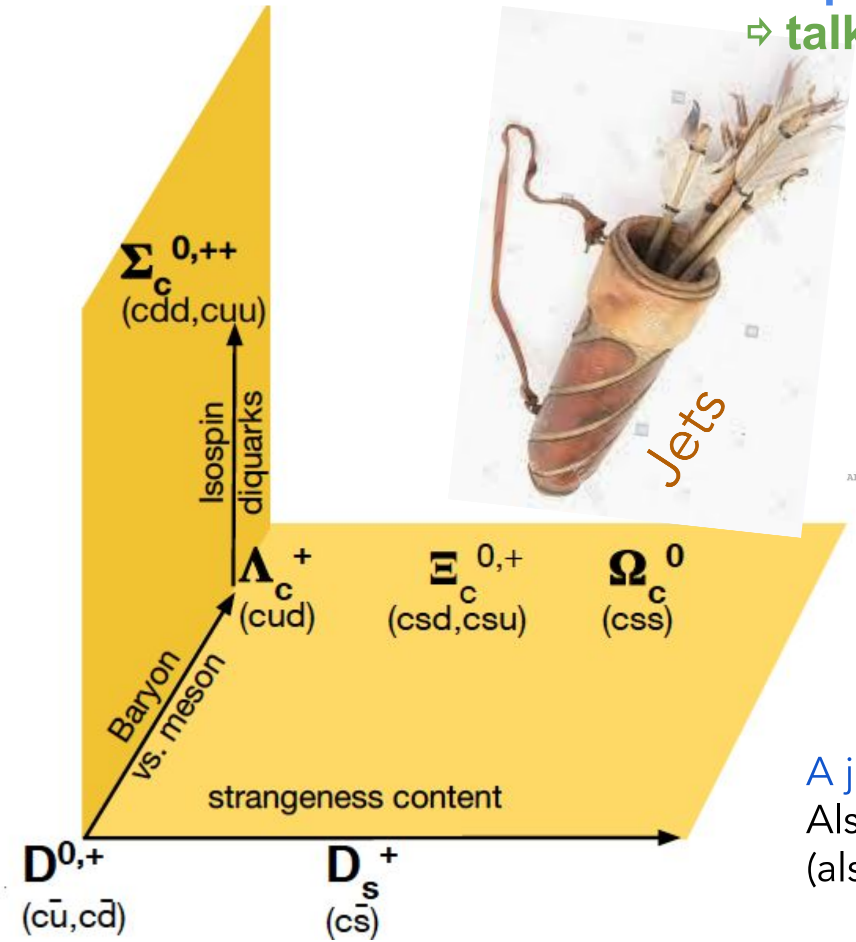


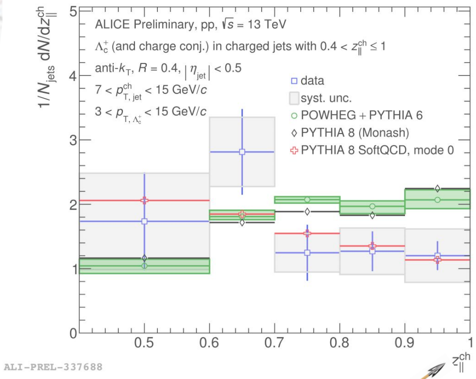


Typically not measurements of cross sections

Several arrows in the quiver

➪ **talks by A. Palasciano, F. Colamaria**



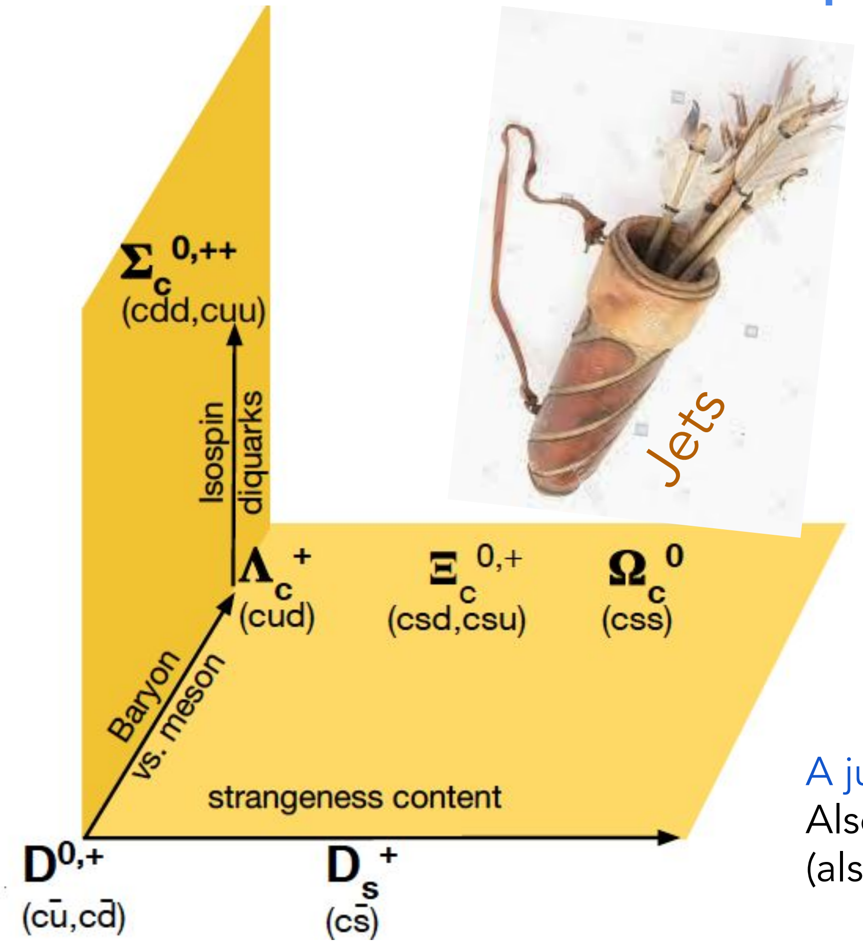


correlations

A jump in mass with beauty!
Also with non-prompt signals
(also leptons and J/Ψ)

Particle	Mass (GeV/c^2)
D^0	1.865
D^+	1.870
D_s^+	1.968
Λ_c^+	2.286
$\Sigma_c^{0,++}$	2.454
Ξ_c^0	2.470
Ξ_c^+	2.468
Ω_c^0	2.695
$B^{0,+}$	5.280
B_s^0	5367
Λ_b^0	5620

Several arrows in the quiver



We can exploit multiplicity

A jump in mass with beauty!
Also with non-prompt signals (also leptons and J/Ψ)

Particle	Mass (GeV/c^2)
D^0	1.865
	1.870
	1.968
	2.286
	2.454
	2.470
$_c$	2.468
Ω_c^0	2.695
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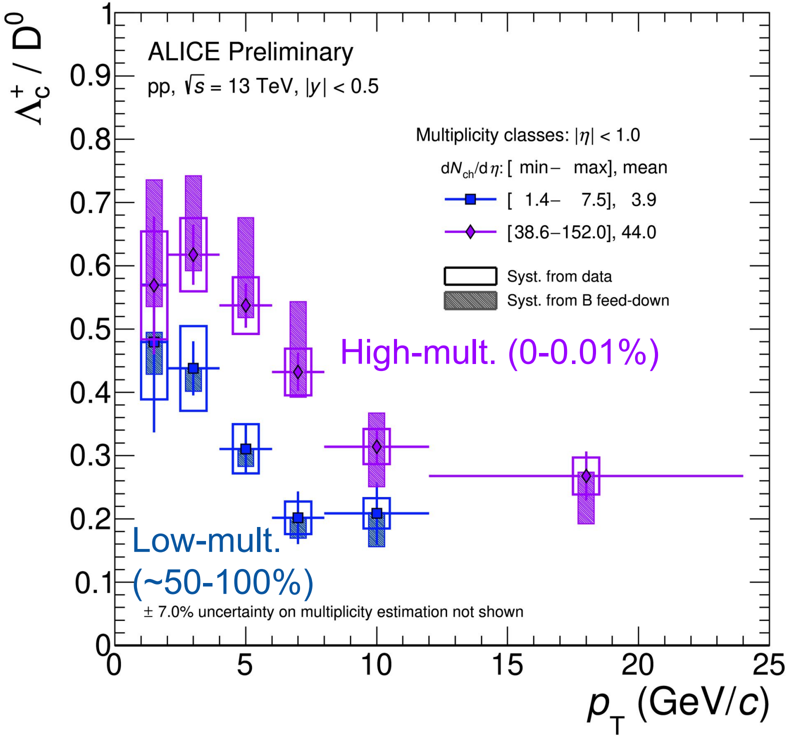
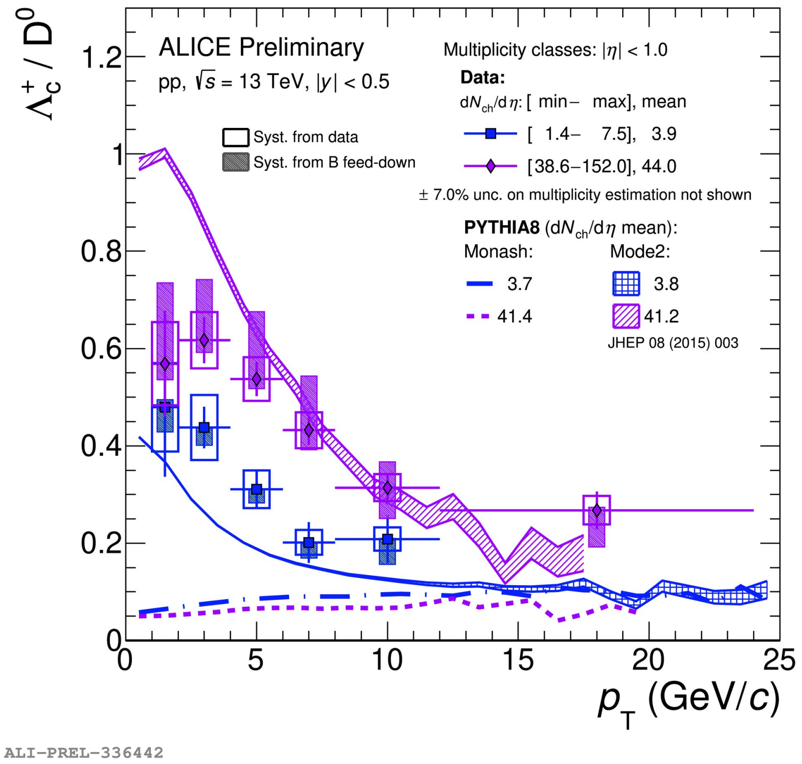
Λ_c^+/D^0 evolution with event activity: pp



ALI-PREL-336418

Λ_c^+/D^0 increases with particle multiplicity at midrapidity

Λ_c^+/D^0 evolution with event activity: pp



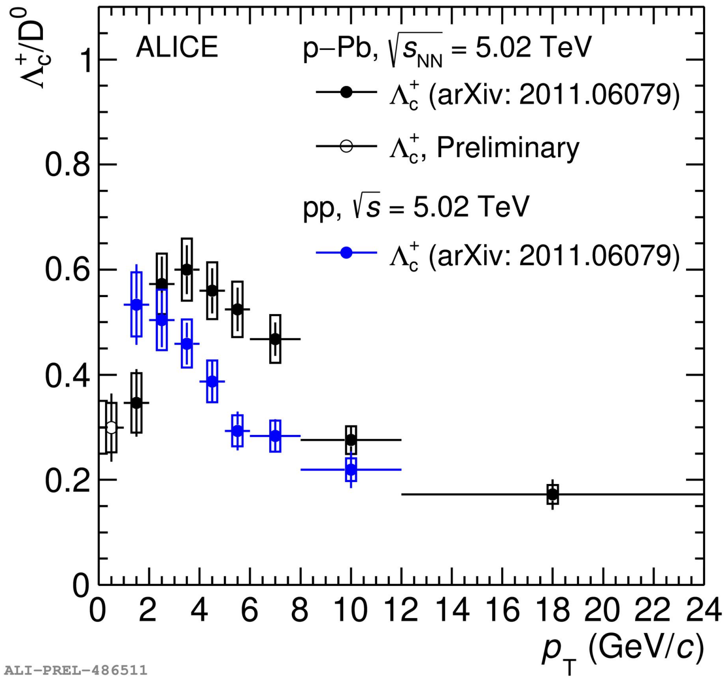
Λ_c^+/D^0 increases with particle multiplicity at midrapidity

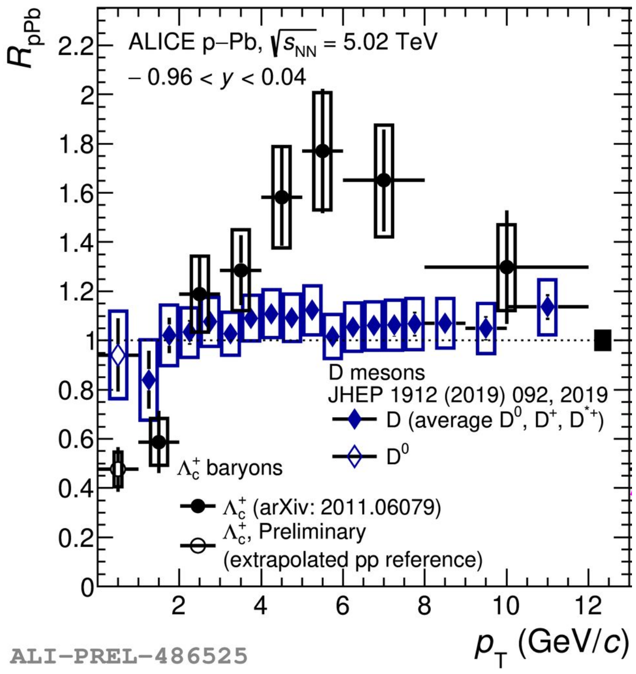
Trend expected by **PYTHIA8 with String Formation beyond Leading Colour (Mode 2)**
→ confirms importance of Colour Reconnection in rich partonic environments
→ **interplay of Color Reconnection (CR) and Multiple Parton Interactions**

Do we have a smooth evolution with multiplicity from (e^+e^- to) pp to AA?

Λ_c^+/D^0 in p-Pb and R_{pPb}

PRC 104 054905 (2021)
PRL 127 202301 (2021)

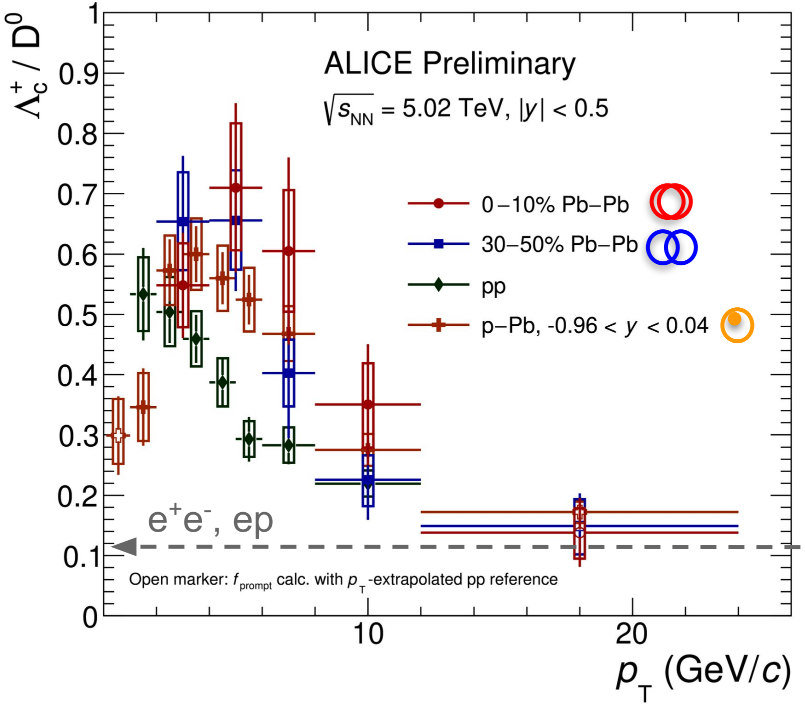




Data suggest modification of Λ_c^+/D^0 ratio from pp to p-Pb

Λ_c^+/D^0 evolution with event activity: from pp to Pb-Pb

More in F. Prino's talk



ALI-PREL-321706

- Λ_c^+/D^0 in Pb-Pb collisions higher than in pp collisions at intermediate p_T
- Similar in 0-10% and 30-50% centrality
- Close to high-multiplicity pp collisions
- **Larger "jump" from e^+e^- to pp than from pp to Pb-Pb**
- **p-Pb in-between pp and Pb-Pb**
  - Measured down to $p_T \approx 0$ → Highlights importance to study evolution of p_T-integrated yield with multiplicity

Heavy flavour hadronization in pp and Pb-Pb

Fragmentation functions universality violated already in pp collisions
Multiple parton interactions in pp build a system rich of quarks or gluons, dense enough to alter hadronisation w.r.t. e^+e^-

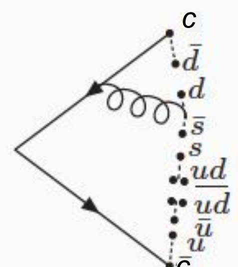
e^+e^- = "vacuum"

pp

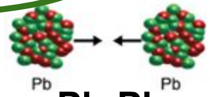
~~not far from vacuum ~ many independent scatterings~~
(for HF at least)

MPI, system size

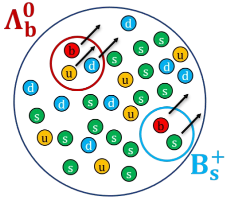
Dynamical model
"Local" dynamical constraints
(e.g. Lund string fragmentation, quarks and diquarks popping out from QCD potential)



Courtesy of C. Bierlich



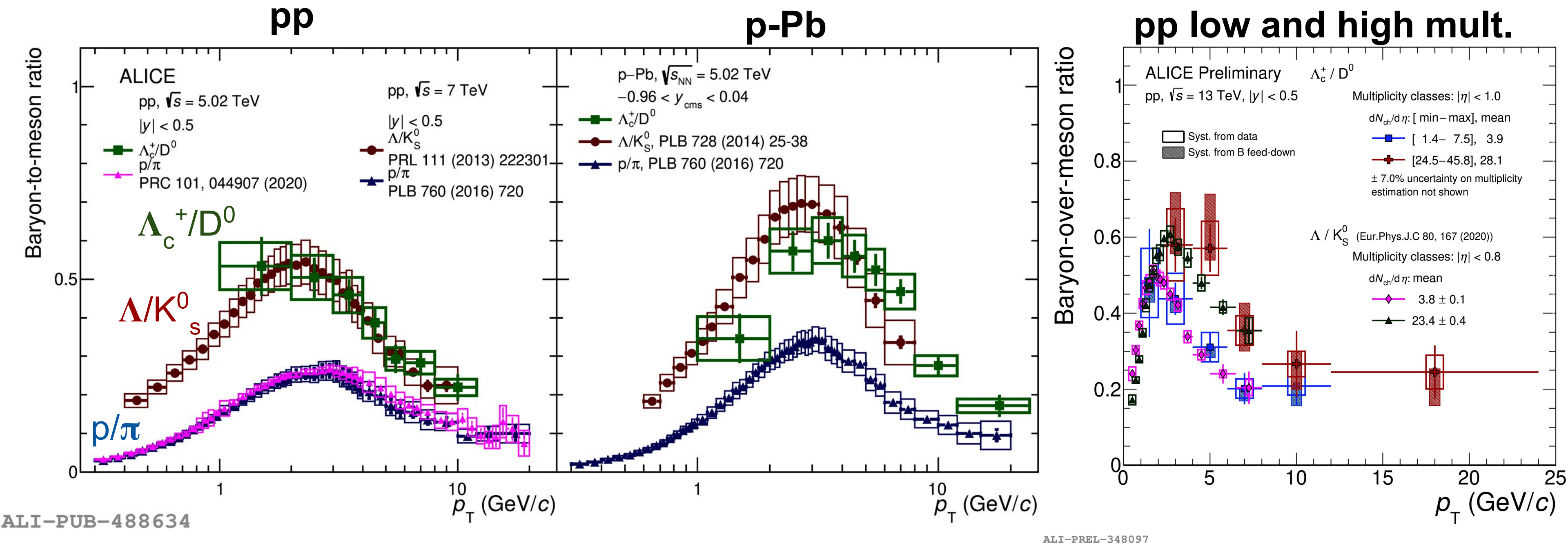
Pb-Pb
Complex, extended-size system,
Local equilibration



(Semi)phenomenological models sufficient to describe relative particle abundances *once ingredients are tuned*?

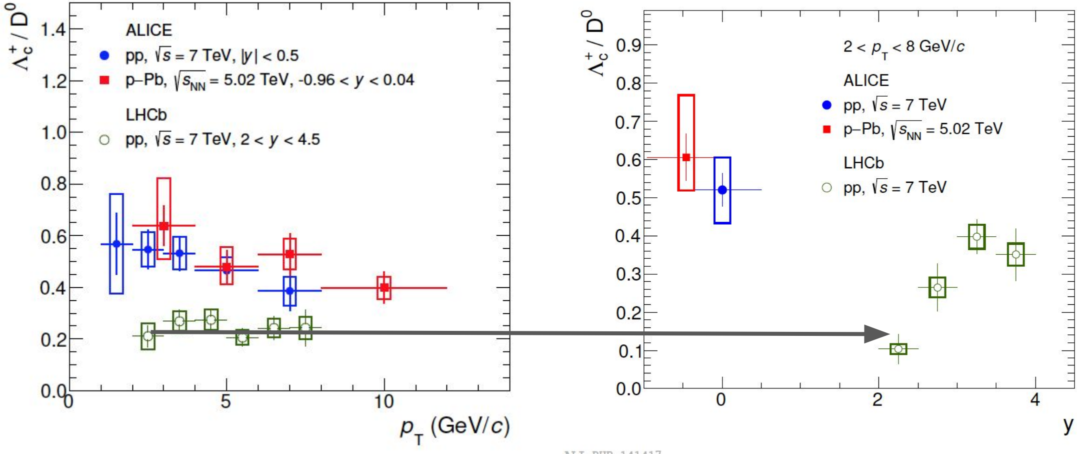
Λ_c^+/D^0 compared with Λ/K_s^0 and p/π^+

PRC 104 054905 (2021)
PRL 127 202301 (2021)



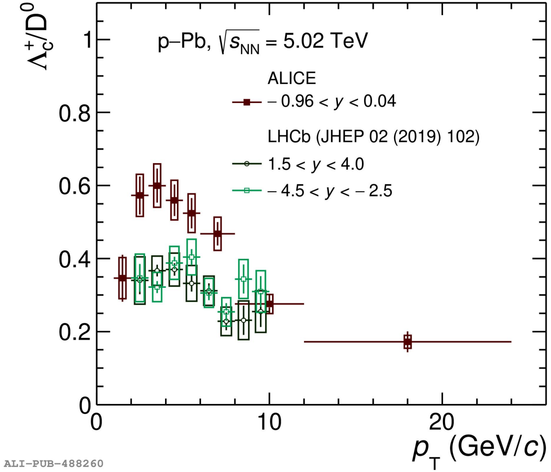
Similar p_T trend and evolution with multiplicity of baryon-to-meson ratios in light and heavy-flavour sector

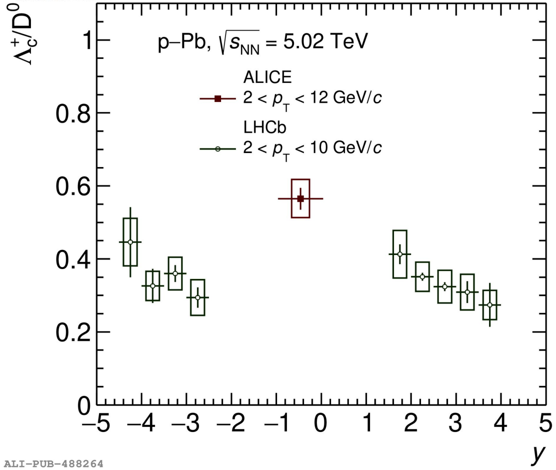
Λ_c^+/D^0 vs. rapidity in pp and p-Pb



ALICE, JHEP 04 (2018) 108, PRC 104 054905 (2021) ,

LHCb (pp), Nucl.Phys.B 871 (2013)
LHCb (p-Pb), JHEP 02 102 (2019)

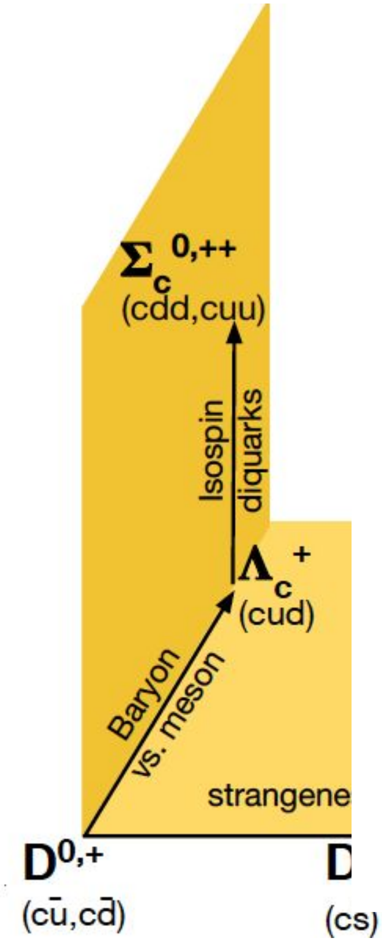


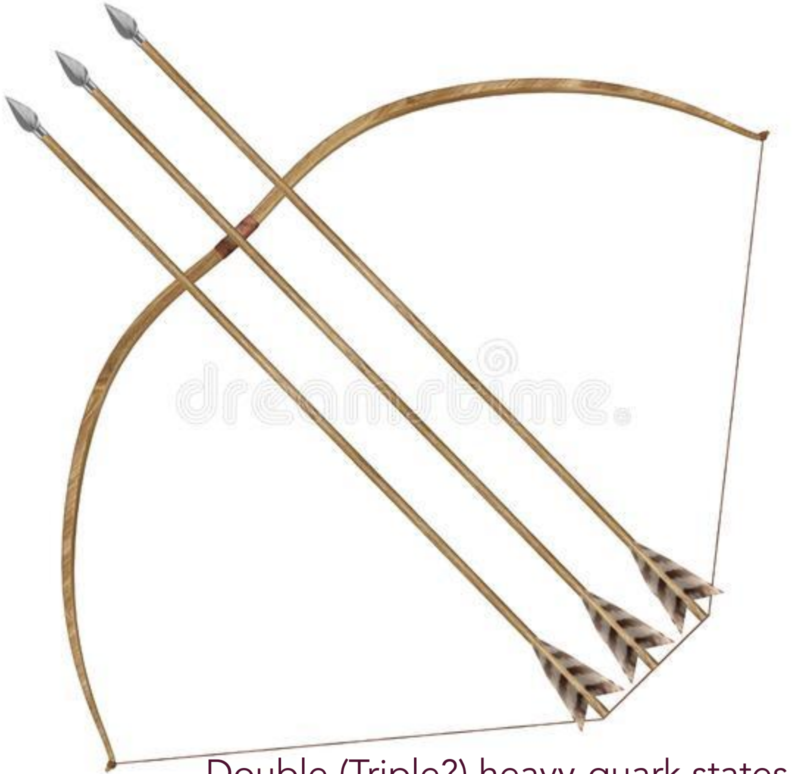


Possible dependence on rapidity, especially in pp collisions

Probably run 3 data needed to clarify

Several arrows in the quiver

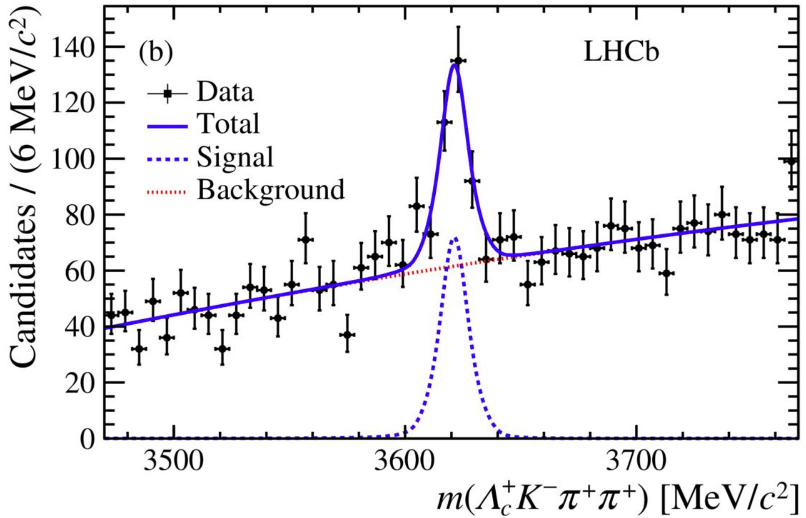




Double (Triple?) heavy-quark states…

Particle	Mass (GeV/c^2)
	1.865
	1.870
	1.968
	2.286
	2.454
	2.470
	2.468
	2.695
	5.280
	5367
	5620

First steps towards measurement of Ξ_c^{++} production



CHIN. PHYS. C44 (2020) 022001

$$\mathrm{BR}(\Xi_{cc}^{++} \to \Lambda_c^+ K^- \pi^+ \pi^+) \times \frac{\sigma(\Xi_{cc}^{++})}{\sigma(\Lambda_c^+)}\bigg|_{4<p_T<15\ \mathrm{GeV}/c} = (2.22 \pm 0.27 \pm 0.29) \times 10^{-4}$$

PYTHIA8 beyond Leading Colour

JHEP 1508 (2015) 003

Primordial yields

Particle	New CR	Old CR
D^+	$5.3 \cdot 10^{-2}$	$6.5 \cdot 10^{-2}$
Λ_c^+	$1.2 \cdot 10^{-2}$	$6.6 \cdot 10^{-3}$
Σ_c^{++}	$1.3 \cdot 10^{-2}$	$5.4 \cdot 10^{-4}$
Σ_c^+	$1.5 \cdot 10^{-2}$	$5.2 \cdot 10^{-4}$
Σ_c^0	$1.3 \cdot 10^{-2}$	$5.1 \cdot 10^{-4}$
Σ_c^{*++}	$2.2 \cdot 10^{-3}$	$9.5 \cdot 10^{-4}$
Σ_c^{*+}	$2.4 \cdot 10^{-3}$	$9.4 \cdot 10^{-4}$
Σ_c^{*0}	$2.2 \cdot 10^{-3}$	$9.1 \cdot 10^{-4}$
ccq^7	$2.1 \cdot 10^{-4}$	$1.0 \cdot 10^{-7}$
B^+	$1.6 \cdot 10^{-3}$	$2.3 \cdot 10^{-3}$
Λ_b^0	$8.2 \cdot 10^{-4}$	$3.9 \cdot 10^{-4}$
Σ_b^+	$9.5 \cdot 10^{-4}$	$3.1 \cdot 10^{-5}$

Double (and triple) charm production can set powerful constraints to hadronisation

As well as to 3-quark potentials (sensitive to "pure 3 quark" force?)

J. Vijande et al., Phys.Rev.D 90 (2014) 9, 094004
Y. Koma et al., Phys.Rev.D 95 (2017) 9, 094513
N. Sakumichi et al., Phys.Rev.D 90 (2014) 11, 111501

Summary

Charm-hadron particle species production and relative abundances powerful probe of hadronisation process in all systems

Overall: large enhancement of charm baryon production relative to charm meson in pp, p-Pb (and Pb-Pb) collisions with respect to e^+e^- and ep collisions

→ **Charm hadronisation involves different processes in hadronic than in e^+e^- and ep collisions**

- **Coalescence** of charm quarks with light quarks from a thermalised and expanding bulk?
- Large effects from **Colour Reconnection** in an environment enriched of coloured partons from MPI

Far from a full understanding:

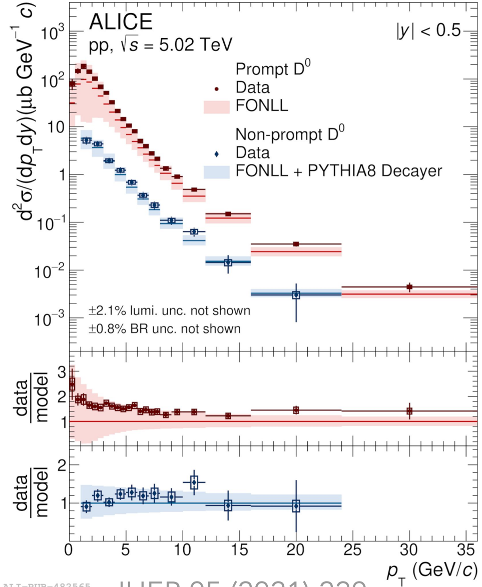
- most of theoretical models do not provide a complete and satisfactory description
- “Catania” model with coalescence in pp closer to the data

New data from incoming **run 3 and run 4 at the LHC** will improve and extend experimental results

Extra

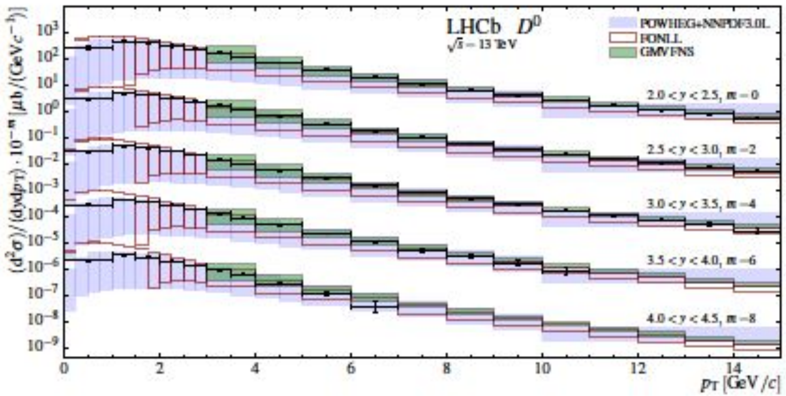
Open heavy-flavour production vs. pQCD

Prompt and non prompt D^0
pp 5 TeV, |y|<0.5



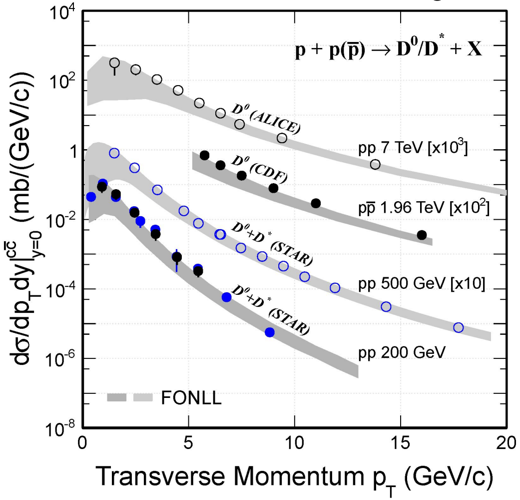
JHEP 05 (2021) 220

Prompt D^0 at forward *y*
pp 13 TeV



JHEP 03 (2016) 159

Prompt D^0 at mid *y*
RHIC, Tevatron, LHC energies



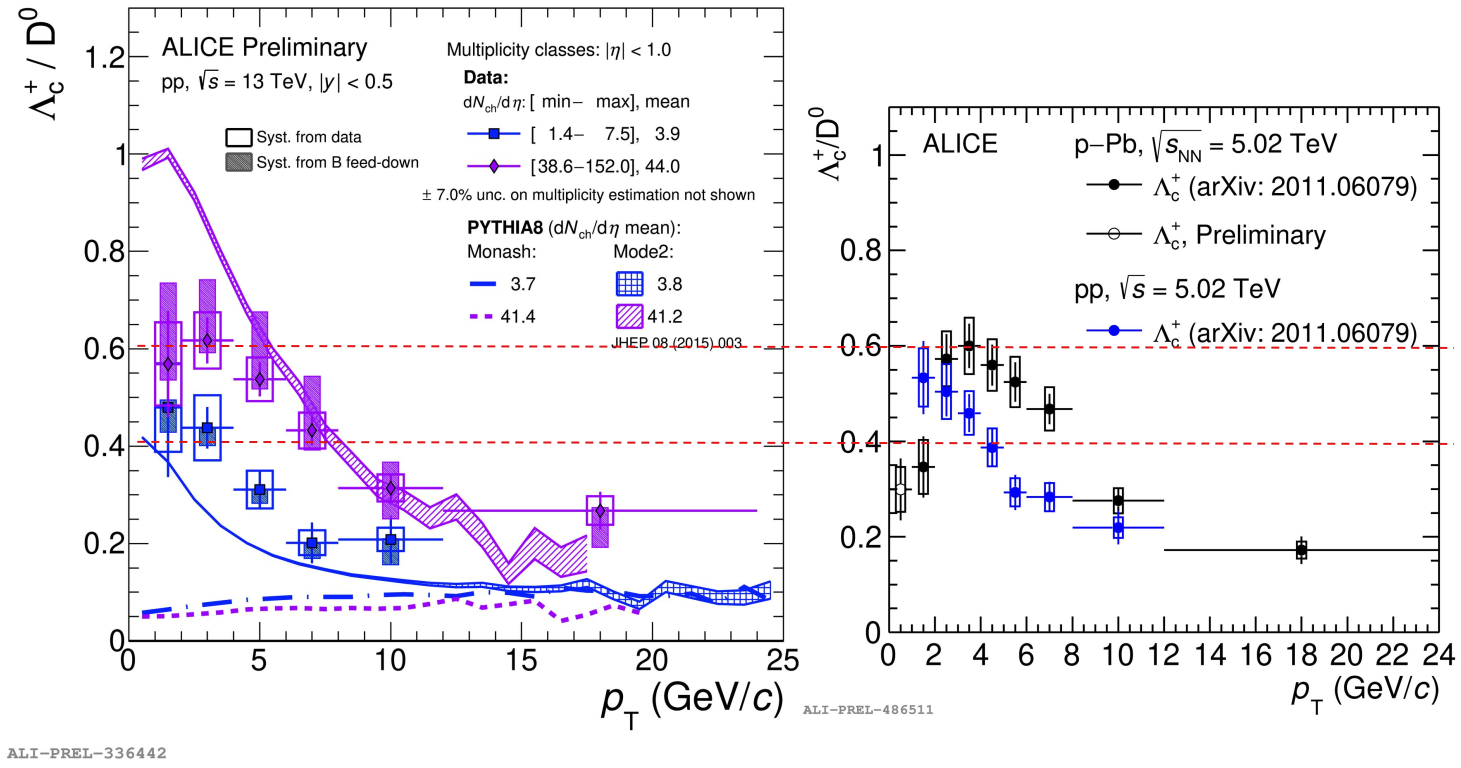
X. Luo et al., JHEP 1909 (2019) 008

Plethora of data indicating that **open-charm and open-beauty meson** production

- vs. p_T and *y* (wide range covered)
- at very different collision energies
- charm meson species relative abundances

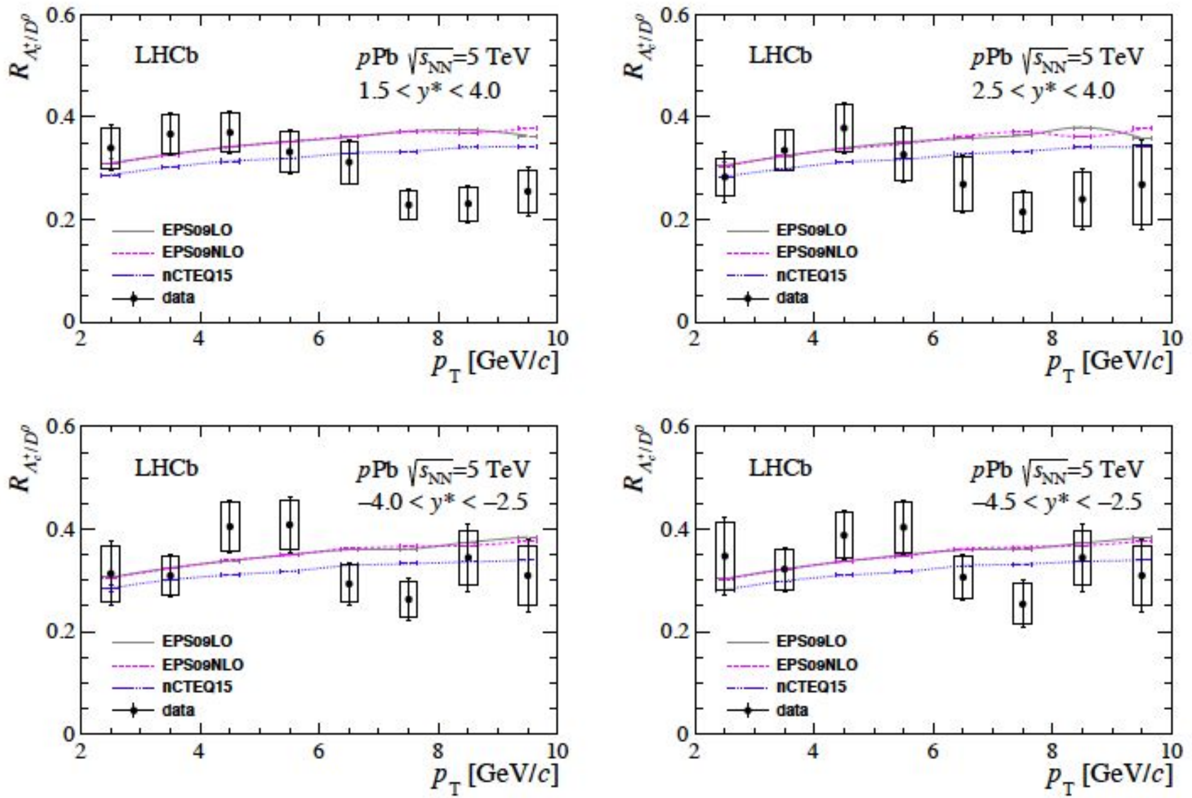
} is **described by pQCD calculations relying on factorisation**

Λ_c^+/D^0 evolution with event activity: pp vs. p-Pb



Λ_c^+/D^0 vs. rapidity in p-Pb collisions

JHEP 02 (2019) 102



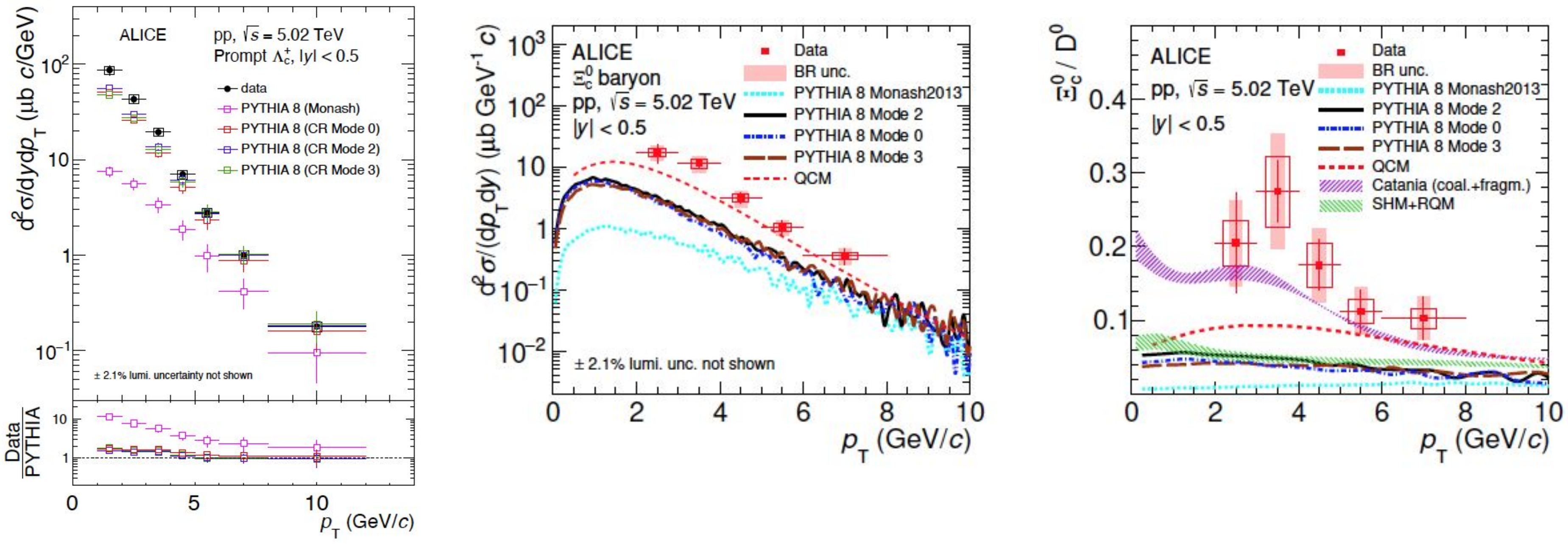
Model comparison: schematic recap

	PYTHIA Monash	PYTHIA BLC	SHM+RQM	QCM	Catania
D^0 cross section			FONLL	FONLL	FONLL
D_s^+/D^0					
Λ_c^+/D^0					
$\Sigma_c^{0,++}/D^0$					
$\Sigma_c^{0,++}/\Lambda_c^+$					
$\Xi_c^{0,+}/D^0$					
$\Xi_c^0/\Sigma_c^{0,++}$					
Ξ_c^0/Λ_c^+					
Ω_c^0/D^0		BR(?)	BR(?)	BR(?)	
Λ_c^+/D^0 vs. mult.			(ongoing)		
Jet properties					

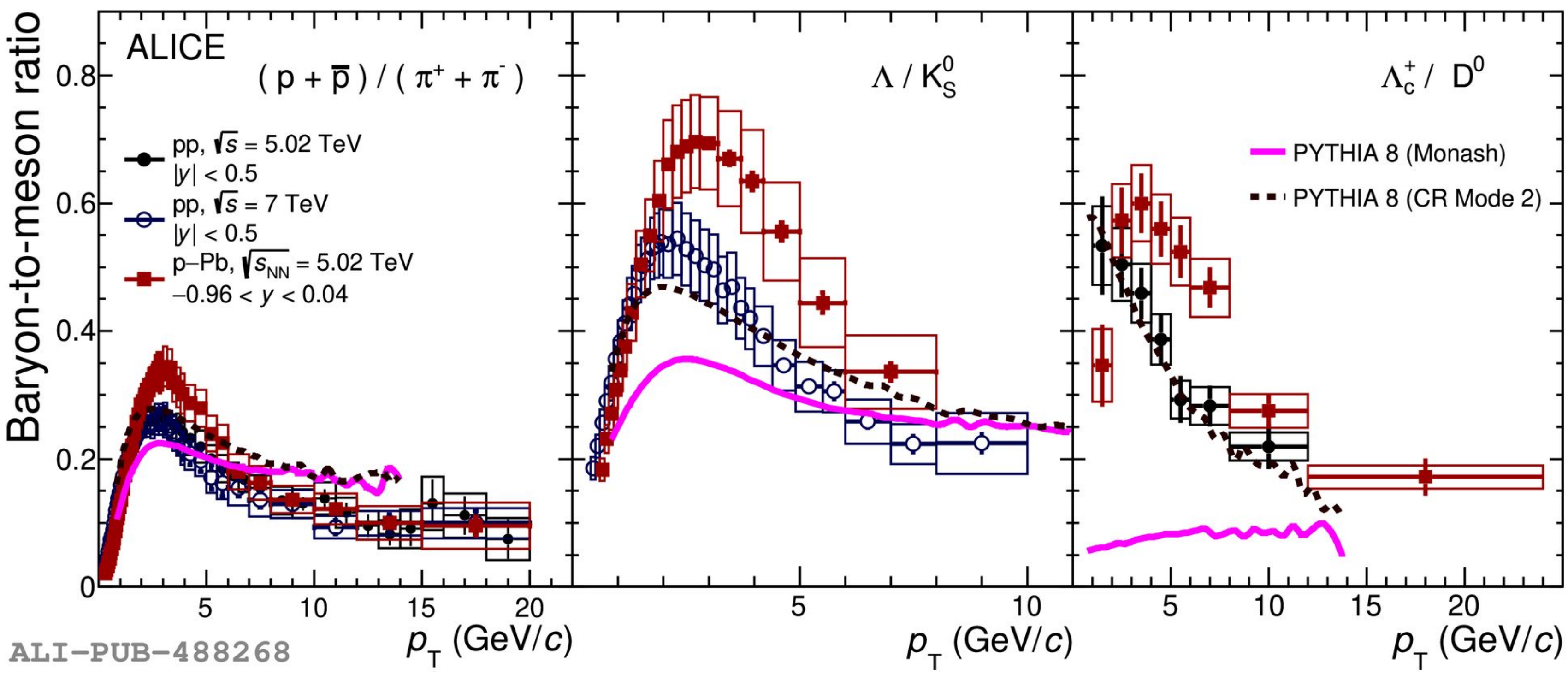
Legend
Ok
Very critical

Not yet
Unavailable

Λ_c^+ and Ξ_c^0 cross section at 5 TeV vs. PYTHIA



Λ_c^+/D^0 compared with Λ/K_s^0 and p/π^+

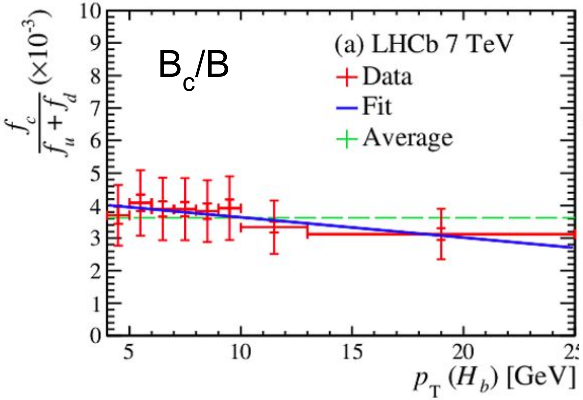


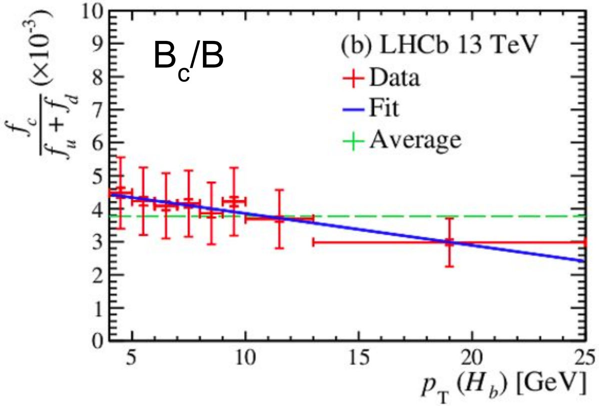
Mass effect or baryon effect?

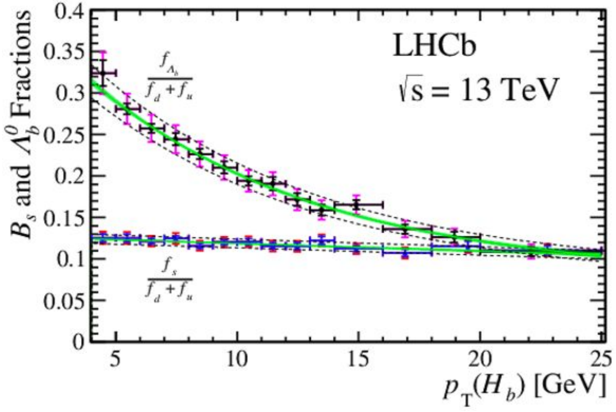
Typically baryons have larger mass
Baryon production requires the production of an antibaryon (→ an antiproton)

⇨ Energy cost larger for baryons than meson → impact on e^+e^- data?

Not main point: similar Λ_c/D at Z^0 and Υ peaks



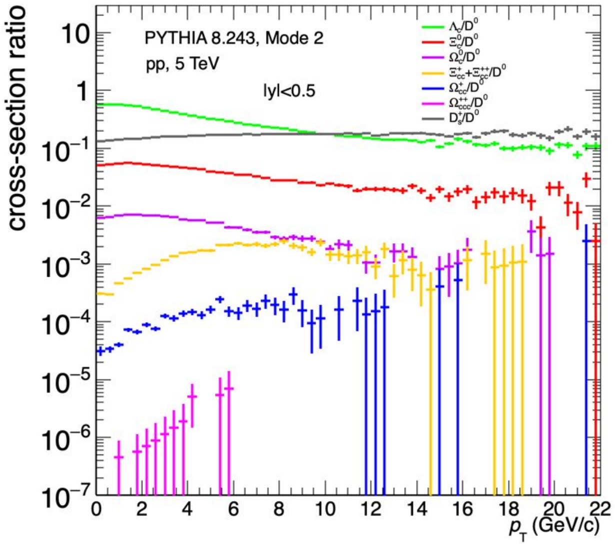


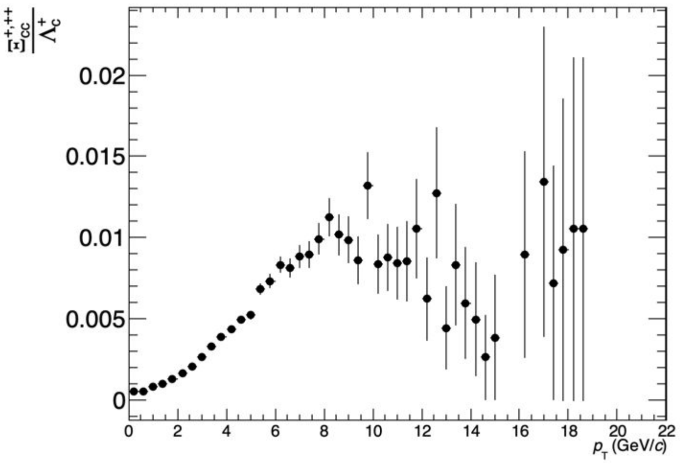


B_c mass >> Λ_b mass + requires another charm meson in the event (D mass >> p mass) → even stronger constraints to phase space from B_c than Λ_b

But **B_c/B shows a much milder p_T trend (if any)** → p_T trend not related to particle mass: does this support a baryon-related effect? (caveat: feed-down, comes later)

First steps towards measurement of Ξ_c^{++} production





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LHCb, CHIN. PHYS. C44 (2020) 022001 :

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